

Aspects of mid-Cretaceous stratigraphical micropalaeontology

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Synopsis

The mid-Cretaceous foraminifera of southern England and northern France have been studied, and the diagnostic species utilized in the formulation of a zonal scheme; the taxonomy of these stratigraphically diagnostic forms is briefly discussed. The zonation has been used in a reappraisal of British mid-Cretaceous stratigraphy. An important non-sequence has been found in the mid-Cenomanian, and this feature has been related to possible changes in the palaeogeography of the North Atlantic Ocean. Two new species, *Plectina cenomana* n. sp. and *Flourensina mariae* n. sp., and one new variety, *Lingulogavelinella globosa* (Brotzen) var. *convexa* nov., are described.

Introduction

This account reviews the micropalaeontological evidence bearing on Cenomanian stratigraphy, and complements similar accounts based on ammonite palaeontology which have appeared during the last few years. In many places the occurrence of foraminifera permits correlation where ammonite evidence is lacking, and comparison of both schemes leads to a more accurate

understanding of the Cenomanian Stage in Great Britain. In areas where the microfaunal and macrofaunal evidence appears to conflict, the disagreements are shown to be due to sedimentological complexity rather than faunal divergence.

It is over eighty years since A. J. Jukes-Browne and W. Hill presented their paper (1896) on 'Delimitation of the Cenomanian' to the Geological Society of London, and until recently this was the most important statement on the British mid-Cretaceous. Although Kennedy's (1969, 1970) work questions some of their theories the majority remain undisputed. Foraminiferal distribution, hitherto largely neglected in studies of British Cenomanian stratigraphy, is here used to check the validity of their proposed correlations. These are amended where necessary and the foraminiferal evidence used to relate the British sequence to the equivalent successions in Europe and North America.

Résumé of Cenomanian research

The Turonian Stage was erected in 1842 by Alcide d'Orbigny for the group of calcareous rocks found in the Touraine (France). D'Orbigny (1842: 404) states: 'Je propose de désigner à l'avant l'étage qui m'occupe (craie chloritée, glauconie crayeuse, craie tuffeau, et grès verts) sous le nom Turonien, de la ville de Tours (Turones) ou de la Touraine (Turonion) situées sur ces terrains.'

After a study of the ammonites and rudists d'Orbigny redefined the Turonian in 1847, thereby erecting a separate stage – the Cenomanian – for the lower part of the original Turonian. Lecomte (1959) designated the Cher Valley as the type section for the redefined Turonian. However, nowhere in the Touraine can a full succession be seen in a continuous exposure, and the outcrops extend from Fréteville to Chisseaux – a distance of some 28 km – along the north side of the Cher Valley. At Fréteville the lowermost Turonian, thin-bedded marly chalk, overlies a sandy marl which in turn rests on glauconitic, oyster-bearing sands. These sands contain abundant *Exogyra columba* (d'Orbigny) and were included by d'Orbigny within the Cenomanian Stage.

The Cenomanian, therefore, was defined as the lower part of the original Turonian and the type area is regarded as the Sarthe region of France. Many sections listed by d'Orbigny have been overgrown or destroyed during the last century, although several new exposures are now available. Guiller (1886) estimated that the Sarthe Cenomanian attained a thickness of 101 m, and this has been corroborated by Juignet (1968), who produced a figure of 100 m for the Cenomanian at Le Mans. In the area immediately east and north of this city the Cenomanian displays so many lateral and vertical facies variations that it is difficult to work out the succession.

Largely through poor exposure the upper levels of the Cenomanian succession are relatively little known. Where recorded their fauna consists mainly of *Ostrea* spp. and *E. columba*, neither of which prove useful for correlation. The lower levels contain a fauna largely of *Exogyra* spp. and other molluscs. These faunas are in a different facies from those of the type Albion of the Aube region of eastern France (Fig. 1) and it is not surprising that correlation difficulties have arisen. As initially defined, the Albion consisted mainly of what is now accepted as Lower Albion and there was little mention of Upper Albion faunas. This led to the erection of the 'Vraconian' Stage for the *Stoliczkaia dispar* Zone.

Between 1840 and 1870 the British Cretaceous was subdivided into lithological units, with only passing reference to the faunas. Details of this early work are summarized in Jukes-Browne & Hill (1900, 1903) and repetition is unnecessary.

Barrois' (1876) study of British Cretaceous stratigraphy used the stage names newly established in France. Many French geologists (Guiller 1886, Hébert 1857, etc.) had difficulty rationalizing d'Orbigny's standard 'stages', and Barrois' attempt at so distant a correlation was thought premature. Jukes-Browne & Hill (1896) clearly outlined their concept of the Cenomanian and this differed from that of Barrois. Barrois included nearly half the Upper Greensand within the Cenomanian Stage, while the English geologists considered the Cenomanian the exact equivalent of the Lower Chalk. In England it had just been accepted that the Gault Clay and the Upper Greensand were lateral equivalents and Jukes-Browne even suggested a name be found for this Gault Clay/Upper Greensand 'Stage' (eventually called the Selbornian). Jukes-Browne & Hill (1896), commenting on the work of Barrois, stated:

'The result of British investigations, therefore, has been to tell us that our subdivisions into Gault, Upper Greensand and Lower Chalk do not tally in any way with their Albien and Cenomanien stages and that if we wished to adopt the French nomenclature we should have to draw a hard and fast line in the middle of the Upper Greensand.

'The work of English geologists has therefore tended to consolidate the Gault and Upper Greensand, and to separate them as a whole from the overlying Lower Chalk, which has generally a bed of glauconitic marl at its base, and is often marked off from the Upper Greensand by a very clear plane of division. The faunal assemblages agree with this method of classification and no modern English geologist would imagine that a more natural division could be made by grouping a part of the Upper Greensand with the Lower Chalk.'

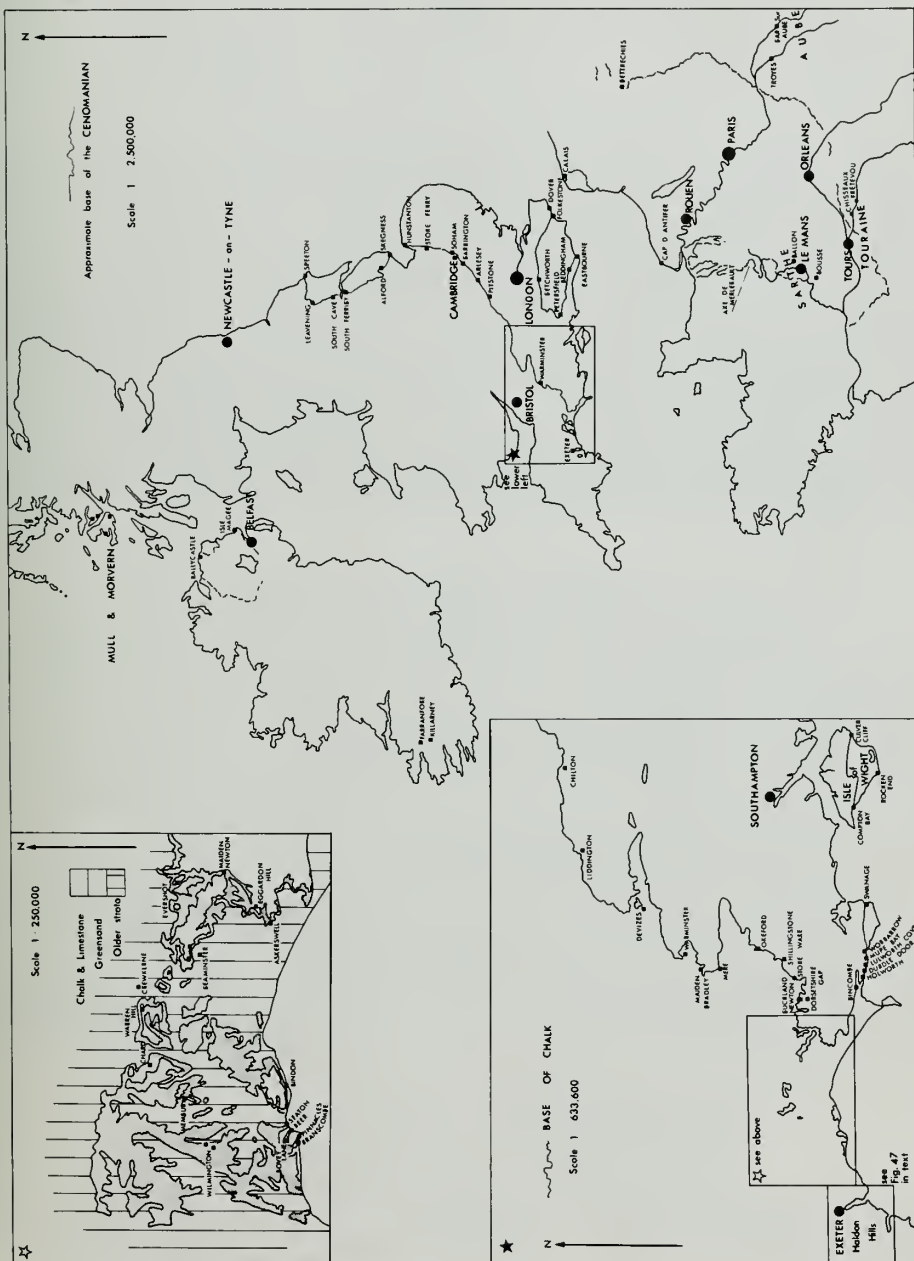


Fig. 1 Locality map of the Anglo-Paris Basin. Inset, western areas of Cretaceous outcrop in more detail.

Since 1896 the lithostratigraphic terms of the English geologists and the chronostratigraphic terms of the French often have appeared side-by-side and both have been much misused. Only sporadic attempts at clarification have been made since 1900. The major contribution of Jukes-Browne & Hill was a series of memoirs on the 'Cretaceous Rocks of Britain' (1900–1904). Their ideas and conclusions are the basis for all later research and only recently have they been critically examined. These books still contain the most complete account yet produced of the British Cretaceous. Spath (1926, 1923–43) and Wright & Wright (1949) produced ammonite zonations for the Albian and Cenomanian. Although the Gault Clay is suitable for such studies the Upper Greensand is not and our knowledge of it has remained largely as it was in Jukes-Browne's time. Smith (1957a, etc.) continued the work of Meyer (1874) in south-west England, and provided very detailed accounts of that rather isolated area of Cretaceous sediments. Unfortunately these marginal deposits were not correlated precisely with the more normal successions of south-east England.

In 1962–63 Jefferies produced two works on the micropalaeontology and stratigraphy of the *Actinocamax plenus* Marls. These showed the advantages of studying a small part of the succession in detail. They demonstrated that apparently uniform chalk may display marked microfaunal changes through quite small stratigraphic thicknesses, and it was partly this approach that inspired the mode of the present research. They permitted tight correlations of the *Plenus* Marls and its use as a reference datum. Other workers in recent years, e.g. Tresise (1960), persisted in using the base of the Lower Chalk as a datum, even after Wright (*in* Arkell 1947) had demonstrated that the base of the Lower Chalk becomes younger towards the south-west of England. However, Jeans (1968), who showed that a series of pulse faunas can be recognized in the Lower Chalk, based his clay mineral distribution diagrams on plotted sections using the *Plenus* Marls as datum.

The last major works were those of Kennedy (1969, 1970), on the ammonite faunas. His studies primarily were of assemblages and, while these have aided our understanding of the Cenomanian, the authors still feel that much of the stratigraphy of the south-west of England remains to be explained. Using both the ammonites and the microfaunas the authors hope to correlate the marginal facies more accurately.

Mid-Cretaceous foraminifera: Systematics

The total foraminiferal population of the mid-Cretaceous includes well over five hundred species. While many of these are stratigraphically useful only a limited number are of major significance. All the species used in the proposed zonation occur in large numbers, and a sample taken from any stratigraphic level would yield the described diagnostic fauna. The only exception is *Conorboides lamplughii* (Sherlock) – the marker for Gault Clay Zone 3 – which can be a little difficult to find unless a large amount of material is processed. These diagnostic species are used in a zonal scheme based on assemblages characteristic of restricted stratigraphic intervals.

The classification of the Foraminiferida has been discussed in detail and the majority of previous classifications analysed by Loeblich & Tappan (1964, *Treatise*). Their classification has been accepted by the majority of micropalaeontologists. The present authors have deviated from it in only a few places, and these are documented. This report primarily is of stratigraphic interest and not intended as a detailed account of foraminiferal taxonomy.

All type and figured specimens, together with some unfigured material, are deposited in the British Museum (Natural History), London, registered numbers P 49941 – P 50040 inclusive.

Order **FORAMINIFERIDA** Eichwald 1830

Suborder **TEXTULARIINA** Delage & Hérouard 1896

Superfamily **LITUOLACEA** de Blainville 1825

Family **ATAXOPHRAGMIIDAE** Schwager 1877

In recent years many workers have become dissatisfied with Loeblich & Tappan's (1964) classification of this family. For a fuller report – particularly regarding *Arenobulimina* Cushman – see

Loeblich & Tappan (1961a) and Gawor-Biedowa (1969). Loeblich & Tappan's classification of the genera considered in this account is as follows:

Subfamily Verneuulininae: *Flourensina* Marie, *Gaudryina* d'Orbigny, *Tritaxia* Reuss.

Subfamily Globotextulariinae: *Arenobulimina* Cushman, *Dorothia* Plummer, *Eggerellina* Marie.

Subfamily Valvulininae: *Plectina* Marsson.

Subfamily Ataxophragmiinae: internally subdivided '*Arenobulimina*' referred to *Ataxophragmium* Reuss or *Hagenowina* Loeblich & Tappan.

Loeblich & Tappan followed Trujillo (1960: 308) in placing *Marssonella* Cushman in the synonymy of *Dorothia* Plummer. In the present work *Marssonella* has been reinstated. They rejected Bowen's (1955: 363) theory that *Gaudryina* d'Orbigny, *Dorothia* and *Marssonella* are congeneric. Although rejection is confirmed here, it must be emphasized that these genera are closely related. A suprageneric classification that divides these three between two subfamilies is quite artificial; we place *Dorothia* and *Marssonella* with *Gaudryina* in the Subfamily Verneuulininae. *Plectina* Marsson is also quite closely related to *Dorothia*, differing only in the terminal position of the aperture. While Loeblich & Tappan state that *Plectina* displays a well-developed valvular tooth, no British specimens have been seen showing this feature. The illustration of *Plectina ruthenica* Reuss given by Loeblich & Tappan does not resemble the type figure and this variance is borne out by subsequent references. Until the type specimens have been re-examined, *Plectina* should be included in the *Gaudryina*, *Dorothia* and *Marssonella* group, i.e. the Subfamily Verneuulininae.

Arguments for changing the classificatory position of *Arenobulimina* have been presented by Gawor-Biedowa (1969). The most important observation is that both *Arenobulimina* Cushman and *Ataxophragmium* Reuss can have either simple or complex interiors and, as they are very similar in both shape and apertural characteristics, it is illogical to place them in different subfamilies. The Subfamily Globotextulariinae therefore has been rejected, and the genus *Arenobulimina* placed in the Subfamily Ataxophragmiinae. It must be emphasized that a complete revision of the Family Ataxophragmiidae is needed. This should include a full analysis of all the available type material.

The provisional reclassification is therefore as follows:

Subfamily Verneuulininae: *Dorothia* Plummer, *Flourensina* Marie, *Gaudryina* d'Orbigny, *Marssonella* Cushman, *Plectina* Marsson, *Tritaxia* Reuss.

Subfamily Ataxophragmiinae: *Arenobulimina* Cushman, *Eggerellina* Marie.

Subfamily VERNEUILININAE Cushman 1911

Genus *DOROTHIA* Plummer 1931

TYPE SPECIES. *Gaudryina bulletta* Carsey 1926.

Dorothia filiformis (Berthelin 1880)

(Plate 1, fig. 3)

1880 *Gaudryina filiformis* Berthelin: 25; pl. 1, fig. 8.

1892 *Gaudryina filiformis* Berthelin; Chapman: 752; pl. 11, fig. 7.

REMARKS. This very thin biserial species usually can be recognized by its small size and almost parallel sides.

RANGE. Middle and Upper Albian, Zones 3-5a; rare with a scattered distribution in Zone 6.

Genus *FLOURENSINA* Marie 1938

TYPE SPECIES. *Flourensina douvillei* Marie 1938.

Flourensina intermedia ten Dam 1950

(Fig. 2)

1950 *Flourensina intermedia* ten Dam: 15; pl. 1, fig. 16.

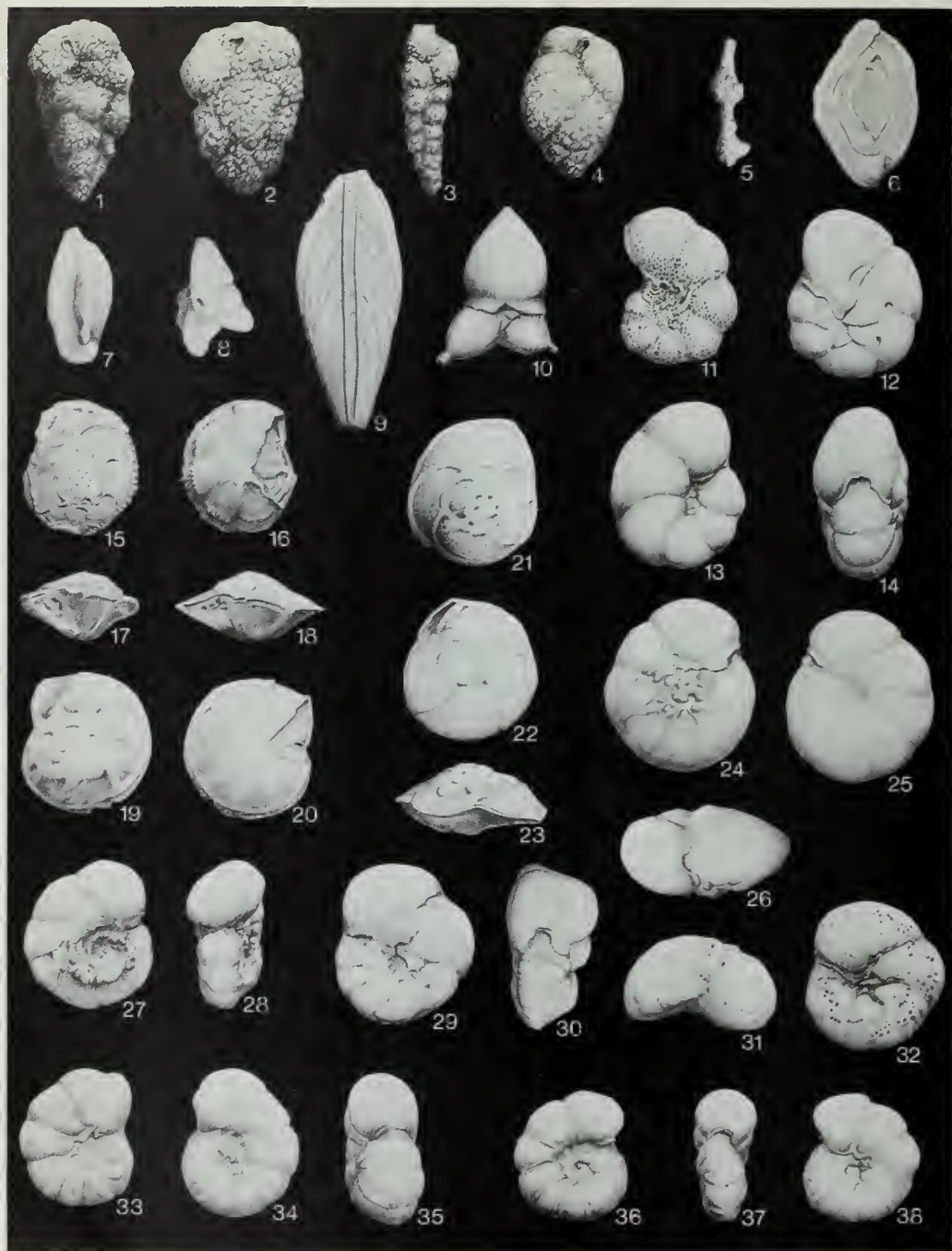


Plate 1

Fig. 1 *Arenobulimina frankei* Cushman. P 49944. Side view. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 38$. (See also Pl. 2, fig. 5.)

Fig. 2 *Arenobulimina sabulosa* (Chapman). P. 49949. Side view. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 32$.

REMARKS. This distinctive triserial species appears fully developed in Zone 6a, and very small, rare, atypical specimens have been found in the lower part of Zone 5a. It has not been recorded farther north than Barrington, Cambridgeshire. The most westerly occurrence is at Beddingham (Sussex). Some badly-preserved specimens of *Flourensina* somewhat similar to this species have been recorded from the sections on the Isle of Wight.

RANGE. Lower Cenomanian chalk and greensand, Zones 6a–8.

Flourensina mariae sp. nov.
(Plate 2, fig. 6)

DERIVATION OF NAME. This species has been named after P. Marie, in recognition of his work on the genus *Flourensina*.

DIAGNOSIS. A *Flourensina* with a loop-shaped aperture, which projects up from the basal suture. The species is characterized by the irregular outline of the later chambers, caused by infolding of the chamber margins.

DESCRIPTION. Test free, agglutinated, coarse-grained, and rough externally; triserial throughout, but chamber arrangement in the late growth stages obscured by the coarse agglutination of the final whorl. Chambers increasing rapidly in size, the last-formed whorl occupying approximately

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- Fig. 3 *Dorothia filiformis* (Berthelin). P 49950. Side view. Middle Albian Zone 4, Bed IV, Copt Point, Folkestone, Kent. $\times 91$.
- Fig. 4 *Arenobulimina chapmani* Cushman. P 49951. Side view. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 34$.
- Fig. 5 *Nodobacularia nodulosa* (Chapman). P 49952. Side view. Upper Albian Zone 5, Bed XI, Copt Point, Folkestone, Kent. $\times 32$.
- Fig. 6 *Spiroloculina papyracea* Burrows, Sherborn & Bailey. P 49953. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 39$.
- Figs 7, 8 *Quinqueloculina antiqua* (Franke). P 49954–5. Side and apertural views. Lower Cenomanian Zone 8, Barrington, Cambridgeshire. Fig. 7, $\times 32$; Fig. 8, $\times 40$.
- Fig. 9 *Citharinella pinnaeformis* (Chapman). P 49958. Side view. Upper Albian Zone 5, Bed XI, Copt Point, Folkestone, Kent. $\times 14$.
- Fig. 10 *Schackoina cenomana* (Schacko). P 49959. Side view. Middle Cenomanian Zone 11(ii), Ackers Steps, Dover, Kent. $\times 141$.
- Fig. 11 *Globigerinelloides bentonensis* (Morrow). Specimen lost by authors. Side view. Middle Cenomanian, Greenhorn Formation, western interior, U.S.A. – supplied by D. Eicher. $\times 91$. (See also Pl. 2, figs 19–20.)
- Figs 12–14 *Lingulogavelinella globosa* (Brotzen). P 49961. Ventral, dorsal and peripheral views. Upper Cenomanian Zone 14 (jia), Compton Bay, Isle of Wight. $\times 48$.
- Figs 15–17 *Hoeglundina carpenteri* (Reuss). P 49964. Dorsal, ventral and peripheral views. Middle Albian Zone 3, Bed III, Copt Point, Folkestone, Kent. $\times 38$.
- Figs 18–20 *Hoeglundina chapmani* (ten Dam). P 49967. Peripheral, dorsal and ventral views. Middle Albian Zone 3, Bed II, Copt Point, Folkestone, Kent. $\times 43$.
- Figs 21–23 *Conorboides lamplughii* (Sherlock). P 49970. Dorsal, ventral and peripheral views. Middle Albian Zone 3, Bed I, Copt Point, Folkestone, Kent. $\times 36$.
- Figs 24–26 *Lingulogavelinella globosa* var. *convexa* nov. P 49972. Ventral, dorsal and peripheral views. Upper Cenomanian Zone 14(i), Merstham, Surrey. $\times 57$.
- Figs 27, 28 *Gavelinella cenomanica* (Brotzen). P 49973. Ventral and peripheral views. Middle Cenomanian Zone 11(i), Compton Bay, Isle of Wight. $\times 32$.
- Figs 29, 30 *Lingulogavelinella jarzevae* (Vasilenko). P 49975. Ventral and peripheral views. Lower Cenomanian Zone 8, East Wear Bay, Folkestone, Kent. $\times 52$.
- Figs 31, 32 *Gavelinella tormarpensis* Brotzen. P 49978. Peripheral and ventral views. Middle Albian Zone 3, Bed II, Copt Point, Folkestone, Kent. $\times 81$.
- Figs 33–35 *Gavelinella intermedia* (Berthelin). P 49981. Ventral, dorsal and peripheral views. Middle Cenomanian Zone 11(ii), Culver Cliff, Isle of Wight. $\times 44$.
- Figs 36–38 *Gavelinella baltica* Brotzen. P 49984. Dorsal, peripheral and ventral views. Upper Cenomanian Zone 14(i), Merstham, Surrey. $\times 30$.

one third of the total length of the test. Margins of the chambers in the late growth stages infolded, giving a crenulate outline to the test in apertural view, and marginal buttresses parallel to the axis of coiling present in the interior. Apertural face flattened, aperture loop-shaped, projecting upwards from the basal suture, in a slight depression.

DIMENSIONS. Holotype – overall height 1.23 mm, overall width 0.75 mm.

LOCALITY AND HORIZON. The holotype (P 49991) is from Middle Cenomanian Zone 12, Buckland Newton, Dorset.

DISTRIBUTION. This species has been found in southern England, extending only as far north as Barrington, Cambridgeshire, and as far west as mid-Dorset.

REMARKS. This Upper Cenomanian species is a late member of the *F. intermedia* lineage. The triserial growth form and the loop-shaped aperture distinguish it as a *Flourensina*, rather than a member of the quadriserial *Arenobulimina anglica* Cushman lineage. *A. anglica* superficially resembles *F. mariae* in showing crenulated chamber margins in the last whorl.

RANGE. Upper Cenomanian chalk (Zones 11(ii)–13); most abundant in Zone 12. The rare specimens found in Zone 14 in the Channel area may be derived.



Fig. 2 *Flourensina intermedia* ten Dam. P 49941. Side view. Sample 51710, Martello Tower No. 3 section, Lower Cenomanian Zone 7, East Wear Road, Folkestone, Kent. $\times 39$.

Comments on the *Flourensina* group

F. intermedia may develop from the *A. sabulosa* (Chapman) lineage (see Fig. 3) high in the Upper Albian by reduction from quadriserial to triserial growth form. However, no intermediate forms have been found. *F. intermedia* is triserial, but the coarse agglutination makes separation from *A. sabulosa* difficult.

F. mariae is unlike any other member of the genus in that the agglutination is not sufficiently coarse to obscure the chamber arrangement, and the outer walls of the later chambers are infolded on lines parallel to the axis of coiling producing buttresses and giving crenulate chamber margins. This infolding is a late development in the *F. intermedia* lineage. However, there is no evidence from Zones 8–11(ii) of any intermediate forms. It is unlikely that *F. mariae* is descended from the *A. anglica* lineage. Although *A. anglica* develops similar internal structures and crenulate chamber margins at the end of its range in Zones 10 and 11(i), the test remains quadriserial. It seems more likely that the formation of the crenulate chamber margins, which is always more marked than in *A. anglica*, is a parallel development.

F. mariae is most abundant in Zone 12 where the associated fauna indicates a shallowing, with erosion in some areas. The development of the buttresses may have been a response to this more turbulent environment. The same level displays a significant, although temporary, reduction in the planktonic population. Although it has not been accurately placed, this level could be the boundary between the Middle Cenomanian (*Acanthoceras rotomagensis* Zone) and the Upper Cenomanian (*Calycoceras naviculare* Zone).

Genus *GAUDRYINA* d'Orbigny in de la Sagra 1839

TYPE SPECIES. *Gaudryina rugosa* d'Orbigny 1840.

Gaudryina austinana Cushman 1936
(Plate 2, fig. 10)

1936 *Gaudryina* (*Siphogaudryina*) *austinana* Cushman: 10; pl. 2, fig. 6a-b.

1937a *Gaudryina* (*Siphogaudryina*) *austinana* Cushman; Cushman: 74, pl. 11, figs 1-3.

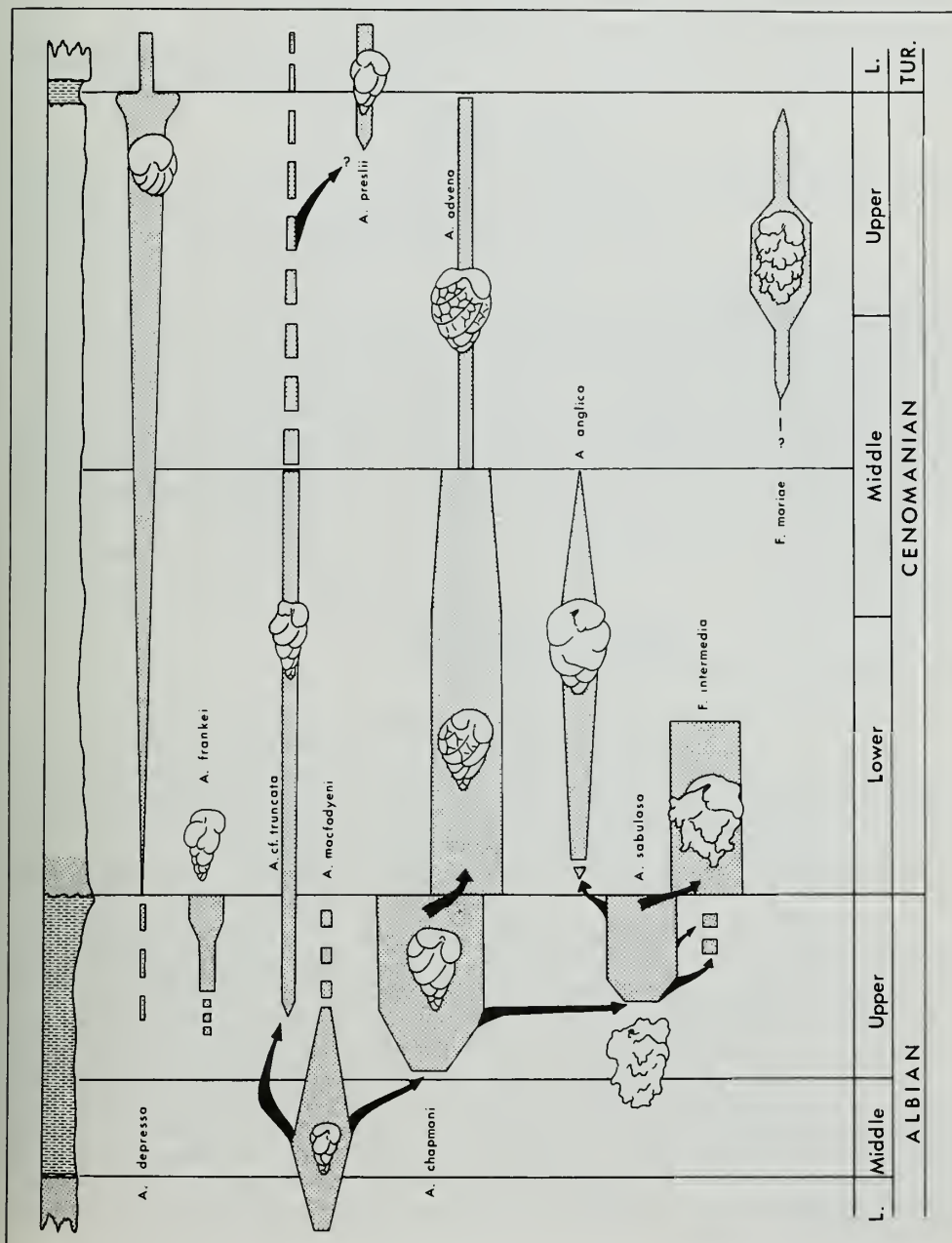


Fig. 3 Evolution of the *Flourensina* and *Arenobulimina* groups.

- 1944 *Gaudryina* (*Siphogaudryina*) *austinana* Cushman; Cushman & Deaderick: 53; pl. 9, figs 15–16
 1946 *Gaudryina* (*Siphogaudryina*) *austinana* Cushman; Cushman: 35; pl. 8, figs 5–7.
 1954 *Gaudryina* (*Siphogaudryina*) *austinana* Cushman; Frizzell: 71; pl. 5, fig. 23a–b.
 1962 *Siphogaudryina* sp. Jefferies: pl. 78, fig. 21a–b.

REMARKS. Although the specimens found in the British Cenomanian are smaller than the types, it is probable that they belong to this species. The characteristic triserial growth stage makes recognition easy, although several specimens have been found in which it is much reduced.

Although this species appears in Zone 6a it only becomes abundant in the lower levels of the Plenus Marls (Bed 1). Within the Cenomanian there are levels of greater abundance (e.g. Zone 12), where there is a suggestion of shallower water conditions.

RANGE. Upper Albian/Cenomanian Zone 6a to Lower Turonian, with levels of greater abundance at the Zone 11(i)/(ii) boundary and in Zones 12 and 14(ia) (Plenus Marls, Beds 2 and 3).

Genus *MARSSONELLA* Cushman 1933

TYPE SPECIES. *Gaudryina oxycona* Reuss 1860.

Marssonella ozawai Cushman 1936 (Plate 2, fig. 1)

- 1936 *Marssonella ozawai* Cushman: 43; pl. 4, fig. 10a–b.
 1937a *Marssonella ozawai* Cushman; Cushman: 59; pl. 6, fig. 18.
 1953 *Marssonella ozawai* Cushman; Barnard & Banner: 205; pl. 19, fig. 2a–b.
 1963 *Marssonella ozawai* Cushman; Barnard: 41–42, text-fig. 1a–c.

REMARKS. Although this species appears in the Upper Albian it is only found in large numbers in the lower levels of the Cenomanian. It can be differentiated easily from its closely related species, *M. trochus* (d'Orbigny), by its coarser agglutination and almost subparallel sides. Rare transitional forms between *M. ozawai* and *M. trochus* occur in the Upper Gault Clay of the Channel area.

RANGE. First appearance in Upper Albian Zone 5a; when present in abundance it is characteristic of Cenomanian Zones 7–9.

Genus *PLECTINA* Marsson 1878

TYPE SPECIES. *Gaudryina ruthenica* Reuss 1851.

Plectina cenomana sp. nov. (Plate 2, fig. 9)

- 1962 *Verneuilina polystropha* (Reuss) Jefferies: pl. 78, fig. 14.

DERIVATION OF NAME. This species is characteristic of the Middle and Upper Cenomanian, and has been used as an indicator of this interval in the proposed zonation.

DIAGNOSIS. The overall triserial appearance of this species differentiates it from other members of the genus.

DESCRIPTION. Test free, of medium-sized agglutinated material with much calcareous cement. Small proloculus followed by two or three trochospiral whorls with up to five chambers in each whorl, and usually forming less than one quarter the length of the test, remainder consisting of two to four whorls of three chambers per whorl, which in adult forms may be followed by a final pair of chambers. This arrangement gives an overall triserial appearance, and although the chambers do not increase rapidly in size the test appears to taper rapidly. Sutures distinct, depressed in the later growth stages, appearance affected by variation in the amount of cementing material. Aperture normally rounded, occasionally oval, positioned in a slight depression in the final chamber; not truly terminal but never interiomarginal, always simple with no teeth or other modifications.

The early growth stages of this species, and the appearance of its aperture, relate it to *P. mariae* (Franke).

DIMENSIONS. Holotype – overall length 0.80 mm, overall width 0.42 mm.

LOCALITY AND HORIZON. The holotype (P 49995) is from Upper Cenomanian Zone 13, Buckland Newton, Dorset.

DISTRIBUTION. This species has been recorded from the Upper Cenomanian of the whole of England (Yorkshire to Devonshire), and from northern France.

REMARKS. While rare juveniles have been seen in the Lower Cenomanian, this species is usually found in the Middle and Upper Cenomanian. In the proposed zonation it is diagnostic of Zones 11 to 13.

RANGE. Middle and Upper Cenomanian Zones 11–13. Very rare specimens have been found in Zone 14(i) (Bed 1 of the Plenus Marls).

Plectina mariae (Franke 1928)

(Plate 2, fig. 8)

1928 *Gaudryina ruthenica* Reuss var. *mariae* Franke: 146; pl. 13, fig. 15a–b.

1937b *Plectina ruthenica* (Reuss) var. *mariae* (Franke) Cushman: 106; pl. 11, fig. 15.

1948 *Plectina ruthenica* (Reuss) Williams-Mitchell: 97; pl. 8, fig. 3.

1962 *Plectina ruthenica* (Reuss); Jefferies: pl. 78, fig. 12.

1972 *Plectina ruthenica mariae* (Franke); Gawor-Biedowa: 34; pl. 3, fig. 3a–b.

REMARKS. The original specimens of *G. ruthenica* from the Senonian appear to possess a more elongate test with many more pairs of biserial chambers than those recorded from the British Isles. Franke, in establishing var. *mariae* for forms with fewer biserial chambers, recorded specimens more closely related to those we have found in our work. Even Franke's specimen, with five pairs of biserial chambers, has more than its British counterparts, which show only three or four. This difference does not warrant specific differentiation. *P. mariae* has not been recorded above the Cenomanian, and as there is no direct link between *mariae* and *ruthenica* both names are retained.

RANGE. Appearing in the basal Cenomanian (Zone 7) this species persists to the top of Bed 1 of the Plenus Marls (Zone 14(i)).

Genus *TRITAXIA* Reuss 1860

TYPE SPECIES. *Textularia tricarinata* Reuss 1844.

Tritaxia pyramidata Reuss 1862

(Plate 2, fig. 15)

1862 *Tritaxia pyramidata* Reuss: 32, 88; pl. 1, fig. 8a–c.

1892 *Verneuillina triquetra* Chapman: 329; pl. 6, fig. 24a–b (*non* Münster).

1892 *Tritaxia tricarinata* Chapman: 749–750; pl. 1, fig. 1a–b (*non* Reuss).

1925 *Tritaxia pyramidata* Reuss; Franke: 18; pl. 2, fig. 1a–c.

1928 *Tritaxia pyramidata* Reuss; Franke: 138; pl. 12, fig. 18a–c.

1931 *Tritaxia pyramidata* Reuss; Plummer: 133; pl. 10, figs 18–20.

1937a *Tritaxia pyramidata* Reuss; Cushman: 22–23; pl. 2, figs 21–24; pl. 3, figs 1–8.

1950 *Tritaxia pyramidata* Reuss; ten Dam: 12–13.

1953 *Tritaxia pyramidata* Reuss; Barnard & Banner: 195; pl. 7, fig. 1a–b, text-figs 5J–N.

1957 *Tritaxia pyramidata* Reuss; Vaptsarova: 45; pl. 2, fig. 3.

1959 *Tritaxia pyramidata* Reuss; Maslakova: 92; pl. 1, fig. 7.

1961 *Tritaxia pyramidata* Reuss; Akimez: 83–84; pl. 3, figs 1a–b, 2.

1962 *Tritaxia tricarinata* (Reuss) var. *pyramidata* Reuss; Jefferies: pl. 78, fig. 3.

1965 *Tritaxia pyramidata* Reuss; Neagu: 5; pl. 1, figs 9–10.

1965 *Tritaxia tricarinata* Reuss; Neagu: 6; pl. 1, figs 7–8, 17–18.

1972 *Tritaxia pyramidata* Reuss; Gawor-Biedowa: 27–28; pl. 1, fig. 10a–b.

REMARKS. This species is characteristic of the Cenomanian (Zones 7–13) and is found in flood abundance in the lower levels of this interval (Zones 7–10). It has not yet been recorded above Bed 3 of the Plenus Marls, although there are Turonian records in the literature. The full range may have to be extended down to Zone 3 of the Middle Albian, although the specimens from these levels are not completely typical of the species as a whole. The chamber arrangement and aperture

are identical with those of forms from the Cenomanian but the agglutination is coarser. Jefferies (1962) illustrated three distinct species of *Tritaxia* from the Plenus Marls as varieties of *T. tricarinata* (var. *plummerae* Cushman, var. *pyramidata* Reuss and var. *macfadyeni* Cushman) but did not differentiate between them in his plots (text-figs 6–11). Specimens from Bed 4 and above belong in his '*T. tricarinata* var. *macfadyeni*', = *T. tricarinata* Reuss s.s.

RANGE. Middle Albian (Zone 3) to Bed 3 of the Plenus Marls (Zone 14(ia)).

Subfamily **ATAXOPHRAGMIINAE** Schwager 1877

Genus **ARENOBULIMINA** Cushman 1927

TYPE SPECIES. *Bulimina preslii* Reuss 1846.

Arenobulimina advena (Cushman 1936)

(Plate 2, fig. 4)

1936 *Hagenowella advena* Cushman: 43; pl. 6, fig. 21a–b.

1937b *Hagenowella advena* Cushman; Cushman: 174; pl. 21, figs 3a–b, 4.

1945 *Hagenowella advena* Cushman; Brotzen: 44–45; pl. 1, fig. 3.

1961 *Hagenowella chapmani* (Cushman); Vasilenko: 22–23; pl. 3, fig. 3a–b; not pl. 4, figs 2a–b, w, 3.

1962 *Hagenowella advena* Cushman; Jefferies: pl. 78, fig. 13.

1969 *Arenobulimina advena* (Cushman) Gawor-Biedowa: 86–90; pl. 8, figs 1–4, text-figs 7, 8.

REMARKS. Brotzen (1945) regards Cushman's statement that the type specimens (of Upper Senonian age) were from 'Junz, near Commin, Pommerania, Germany', was erroneous, and suggests that the actual locality must have been 'Zunz, near Kammin, Pommerania'. The beds at this locality are Upper Cenomanian (Brotzen 1942), and in agreement with our recorded distribution.

Although externally almost identical with *A. chapmani* Cushman, this species can easily be identified by the complex pattern of internal marginal partitions developed in the later chambers. On the external surface the partitions appear as light and dark bands, and can also be studied by breaking the specimens, or treatment with very weak acid. There is complete transition between this species and *A. chapmani* at or about the Albian-Cenomanian boundary within Zone 6a, and this appears to be unaffected by facies changes. Throughout the Cenomanian there is a transition from forms with relatively simple internal partitions to those with a complex pattern of small chamberlets, and from a study of the type of internal subdivision the position of any specimen within the Cenomanian sequence can be roughly estimated.

The overall shape of the test is very variable and ranges from long and thin to short and round. Shape differences may be because two generations are present. Close examination has shown that the long, slender specimens are microspheric.

RANGE. Upper Albian/Lower Cenomanian (Zone 6a) to Upper Cenomanian Zone 14(i) (Plenus Marls Bed 1). This species is most abundant in the Lower Cenomanian Zones 7–10.

Arenobulimina anglica Cushman 1936

(Plate 2, fig. 3)

1936 *Arenobulimina anglica* Cushman: 27; pl. 4, fig. 8a–b.

1937b *Arenobulimina anglica* Cushman; Cushman: 37; pl. 4, figs 31, ?32, not 33, 34.

1947 *Arenobulimina anglica* Cushman; Grekoff: 2; pl. 1, fig. 5a–b.

REMARKS. This species was initially described from the Chalk Marl detritus of Charing, Kent, and the holotype is typical of specimens found in the lower part of the Chalk Marl sequence. However, Cushman's (1937b) paratype (fig. 32) is very like *A. obliqua* (d'Orbigny) and the other specimen (fig. 33) is internally subdivided and should be included in *A. advena*. Although the holotype shows no sign of internal subdivisions, specimens from higher levels of the Chalk Marl (Zone 10) show a slight folding of the margins of the later chambers, similar to that already described in *F. mariae*.

RANGE. Lower Cenomanian Zones 8–11(i), although rare specimens have been found in Zones 7 and 11(ii). Specimens apparently transitional to *A. sabulosa* occur in Zone 6a.

Arenobulimina chapmani Cushman 1936

(Plate 1, fig. 4)

- 1892 *Bulimina preslii* Chapman: 755; pl. 12, fig. 4 (*non* Reuss).
1936 *Arenobulimina chapmani* Cushman: 26; pl. 4, fig. 7a–b.
1937b *Arenobulimina chapmani* Cushman; Cushman: 36; pl. 3, figs 27–28.
1947 *Arenobulimina chapmani* Cushman; Grekoff: 493; pl. 1, fig. 1a–b.
1950 *Arenobulimina chapmani* Cushman; ten Dam: 14.
1955 *Arenobulimina preslii* (Reuss) 1851 et aff. sp.; Bettenstaedt & Wicher: 503; pl. 4, fig. 29.
1962 *Arenobulimina preslii* (Reuss); Bartenstein & Bettenstaedt: 290; pl. 41, fig. 5; text-fig. 18.
1965 *Arenobulimina chapmani* Cushman; Neagu: 10; pl. 2, fig. 9.
1969 *Arenobulimina chapmani* Cushman; Gawor-Biedowa: 81–84; pl. 5, figs 1a–b, 2; pl. 7, figs 1a–b, 2; text-figs 3, 4.

REMARKS. This species is remarkable for its almost total lack of variation. The only significant difference is in the number of chambers in the final whorl of mature specimens – four in the lower and five in higher zones. *A. chapmani* was first recorded by Chapman from Beds VI–XIII of the Gault Clay sequence at Copt Point, Folkestone. In areas where Zone 6a is wanting there is a very marked change in the population between Zones 6 and 7 – the latter containing forms with internal partitions, placed in *A. advena*. Where Zone 6a is present there is a transition between the two species.

RANGE. Albion Zones 4a–6a.

Arenobulimina frankei Cushman 1936

(Plate 1, fig. 1; Plate 2, fig. 5)

- 1936 *Arenobulimina frankei* Cushman: 27; pl. 4, fig. 5a–b.
1937b *Arenobulimina frankei* Cushman; Cushman: 37–38; pl. 4, fig. 21a–b.
1947 *Arenobulimina frankei* Cushman; Grekoff: 494; pl. 1, fig. 2a–b.
1957 *Arenobulimina frankei* Cushman; Mikhailova-Jovtheva: 103; pl. 1, fig. 14a–b.
1969 *Arenobulimina frankei* Cushman; Gawor-Biedowa: 84–86; pl. 5, figs 4, 5; pl. 7, figs 6, 7a–b, 8a–b; text-figs 5, 6.

REMARKS. This species has an almost triangular, 'wedge-shaped' test, which is uniformly triserial throughout all the growth stages. *A. frankei*, initially described from the Cenomanian of Hildesheim (now Mierczany, Poland), was almost twice the size of the British specimens, although they are probably conspecific. Gawor-Biedowa gave the range in Poland as Upper Albion and Cenomanian with a size variation that would include the British specimens. Her comparative material comes from the same region as Cushman's.

RANGE. Rare juveniles appear in the lower part of Upper Albion Zone 6 but large numbers are found only in its upper levels. It persists into Zone 6a but is only found near the base.

Arenobulimina macfadyeni Cushman 1936

(Plate 2, fig. 2)

- 1892 *Bulimina orbignyi* Chapman: 754; pl. 12, fig. 2 (*non* Reuss).
1936 *Arenobulimina macfadyeni* Cushman: 26; pl. 4, fig. 6a–c.
1937b *Arenobulimina macfadyeni* Cushman; Cushman: 35; pl. 4, figs 13, 14.
1950 *Arenobulimina macfadyeni* Cushman; ten Dam: 14.
1965 *Arenobulimina macfadyeni* Cushman; Neagu: 10; pl. 2, figs 7, 8.
1967 *Arenobulimina macfadyeni* Cushman; Uguzzoni & Radrizzani: 1201; pl. 88, figs 7, 8.

REMARKS. This small species is common in the Lower Gault Clay (Middle Albion), and at its maximum development in Beds VII–VIII. In the Upper Albion occasional specimens are found which are much larger and which possess more coarsely agglutinated tests. These are thought to be later members of the same group.

RANGE. While this species is recorded from the Middle Albion Zones 3, 4 and 4a, it has also been found in the Lower Greensand, and its earliest occurrence cannot be placed accurately. Although

specimens have been found from higher levels in the Albian they are atypical and have not been used in the zonation.

Arenobulimina sabulosa (Chapman 1892)

(Plate 1, fig. 2)

- 1892 *Bulimina preslii* Reuss var. *sabulosa* Chapman: 755; pl. 12, fig. 5.
1934 *Arenobulimina sabulosa* (Chapman) Cushman & Parker: 32; pl. 6, fig. 6a-b.
1937b *Arenobulimina sabulosa* (Chapman); Cushman: 36; pl. 3, figs 29, 30.
1947 *Arenobulimina sabulosa* (Chapman); Grekoff: 499; pl. 2, fig. 3a-b.
1957 *Verneulinoides borealis* Tappan; Tappan: 206; pl. 66, fig. 16, not figs 10-15, 17-18.
1967 *Arenobulimina sabulosa* (Chapman); Kaptarenko-Chernousova: 74; pl. 14, fig. 2a-b.
1969 *Arenobulimina sabulosa* (Chapman); Gawor-Biedowa: 77-80; pl. 5, fig. 3; pl. 7, fig. 3a-b; text-figs 1-2.

REMARKS. Chapman (1898, Appendix 3) states that this form is restricted to Beds XII and XIII of the Copt Point succession. In the USSR (Dnieper - Don depression) there are records of Cenomanian occurrences, as well as Albian to Cenomanian records for the central Volga region. The range of Upper Albian to Cenomanian has also been recorded from Poland. In Britain there is no evidence that this species persists into the Cenomanian, although redeposited specimens may occur at the base, in Zone 7. This quadriserial species is usually easily recognized, although an increase in the coarseness of the agglutination can cause some confusion with *F. intermedia* ten Dam.

RANGE. Upper Albian Zones 5a and 6; Upper Albian/Lower Cenomanian Zone 6a.

Comments on the *Arenobulimina* group

A. macfadyeni is the only member of the *Arenobulimina* plexus in the basal Gault Clay (Middle Albian). Throughout the Middle Albian there is very little change in this species apart from a slight increase in size of the adult specimens. At, or about, the Middle/Upper Albian boundary at Folkestone diversification of the group begins, see Fig. 3, p. 11. The two new species appearing at this level give very little indication of their origin, although it is probable that one, the numerically important *A. chapmani*, developed from the *A. macfadyeni* lineage. The origin of *A. frankei* is uncertain, and it is possible that this species does not belong in the *Arenobulimina* plexus. It has a very restricted range, and while primitive forms are recorded from Upper Albian Zone 5, it is otherwise confined to Upper Albian Zone 6. In Zone 6a it evolves into the typically Cenomanian *Plectina mariae*. *A. chapmani* is ancestral to the majority of the Cenomanian species and is also dominant in the Upper Albian. In the uppermost Albian some very coarsely agglutinated specimens are found, while others increase steadily in size. This is the first sign of the separation into the two lineages seen in the lower levels of the Cenomanian. The *A. chapmani* group continues across the Albian/Cenomanian boundary with little, if any, change in external morphology. However, there are marked internal differences. Those from the Cenomanian are always seen to have developed a complex pattern of internal structures, typical of the species *A. advena*. This transition from *A. chapmani* to *A. advena* is always observed at the Albian/Cenomanian boundary irrespective of facies. In the basal Cenomanian these internal structures are essentially simple, marginal partitions, but at higher levels more and more complex modifications appear. The progression is not steady, as examples of the simpler forms occur at all levels within the Cenomanian. In the lower levels of the Plenus Marls (Zone 14(i), Bed 1) all variations from the very simple to the highly complex forms occur. The internally subdivided forms then disappear suddenly and do not persist into the Turonian.

Those specimens of *A. chapmani* that develop a much coarser test in the upper levels of the Albian gradually alter their chamber arrangement until they are referable to the typically quadriserial species *A. sabulosa*. This is recorded from Upper Albian Zones 5a, 6 and 6a. Others become triserial and, near the top of Zone 5a, give rise to the first, small, rare specimens of *Flourensina intermedia*. Just below the Cenomanian boundary *A. sabulosa* gives rise to *A. anglica*, through the intermediate forms seen in Zone 6a.

Small, rounded forms which show no apparent relationship to any of the above-mentioned species are present throughout the whole of the Albian and Cenomanian. Although they are thought to represent immature, megalospheric individuals of one or more of the above groups, no direct relationship can be proved. No attempt has been made to assign any of these forms to particular species as they appear to be of no stratigraphic value.

Genus *EGGERELLINA* Marie 1941

TYPE SPECIES. *Bulimina brevis* d'Orbigny 1840.

Eggerellina mariae ten Dam 1950
(Plate 2, fig. 7)

1950 *Eggerellina mariae* ten Dam: 15–16; pl. 1, fig. 17.

1962 *Eggerellina* sp. Jefferies: pl. 79, fig. 5.

1972 *Eggerellina mariae* ten Dam; Gawor-Biedowa: 33–34; pl. 3, figs 1a–b, 2a–b.

REMARKS. This is a very variable species and completely accurate references are almost impossible without further study. The external shape varies from short pyramidal to long and narrow. It is probable that this species is ancestral to *E. intermedia* (Reuss), which is commonly recorded from higher levels in the Cretaceous.

At certain levels within the Cenomanian, particularly in the lower horizons of the Plenus Marls, there are several varieties of *Eggerellina* present in almost every sample. On morphology alone these could be placed in several 'species' and varieties (*E. brevis* (d'Orbigny) var. *conica* Marie, *E. murchisoniana* (d'Orbigny), *E. cf. E. puschi* (Reuss), etc.). In our opinion these are intergrading variants of a single plexus which begins with *E. mariae* in the Albian and leads to *E. intermedia* in the Senonian. Other generic groups develop numerous variants in the Plenus Marls and we suggest that the extreme variation seen at this level is ecophenotypic.

RANGE. This species appears in the uppermost levels of Zone 5 (Upper Albian), becomes abundant in Zone 5a, and continues in varying numbers throughout the Cenomanian into the Lower Turonian.

Family ORBITOLINIDAE Martin 1890

Genus *ORBITOLINA* d'Orbigny 1850

TYPE SPECIES. *Orbitolites lenticulata* Lamarck 1816, = *Madreporites lenticularis* Blumenbach 1805.

Orbitolina lenticularis (Blumenbach 1805)

1805 *Madreporites lenticularis* Blumenbach: pl. 80, figs 1–6.

1816 *Orbulites concava* Lamarck: 197.

1816 *Orbulites lenticulata* Lamarck: 197.

1850 *Orbitolina lenticulata* (Lamarck) d'Orbigny: 143, no. 342.

1850 *Orbitolina concava* (Lamarck) d'Orbigny: 185, no. 745.

1900 *Orbitolina concava* (Lamarck); Egger: 145; pl. 22, fig. 34; pl. 24, figs 38–40; pl. 26, figs 1–18.

1948 *Orbitolina cf. concava* (Lamarck); Henson: 61; pl. 4, figs 5–10; text-fig. 10j–r.

1960 *Orbitolina concava* (Lamarck); Douglass: 32; pls 2, 3.

1963 *Orbitolina lenticularis* (Blumenbach); Hofker: 181–302, figs 1–24, charts 1–9, pls 1–23, and full synonymy.

REMARKS. *Orbitolina* has been recorded from strata of Barremian to Cenomanian age in the Tethyan Province, although its range in other parts of the world is somewhat shorter. The first 'Linnaean' name applied to the group was *Madreporites lenticularis* Blumenbach (1805). This was followed in principle by later workers, although various generic names (*Orbulites* Lamarck, *Orbitolites* d'Archiac) have been proposed. The genus *Orbitolina* was established in 1850 by d'Orbigny, and this name is used in preference to the earlier generic names for reasons given by Hofker (1963) and Loeblich & Tappan (1964). The early work on the differentiation of species within the genus was based on external characteristics (height, diameter, etc.). Douvillé (1904) was the first to propose the use of internal characters for taxonomic work, and this was done by



Plate 2

Fig. 1 *Marssonella ozawai* Cushman. P 49987. Side view. Lower Cenomanian Zone 8, East Wear Bay, Folkestone, Kent. $\times 48$.

Fig. 2 *Arenobulimina macfadyeni* Cushman. P 49988. Side view. Middle Albian Zone 3, Bed I, Copt Point, Folkestone, Kent. $\times 51$.

Henson (1948), Douglass (1960), Ayala-Castanares (1960) and Schroeder (1962). Hofker (1963) proposed the complete subdivision of the genus into 'form groups' on the basis of the megalospheric embryonic apparatus.

The detailed account of the morphology provided by Hofker (1963) is so complete that very little can be added. However, the particular 'form group' to which the British specimens can be assigned is discussed in detail, since the location of its position in the stratigraphic sequence is important in this research. Hofker recognized that it is only the initial chambers of the megalospheric individuals that give any indication of the correct placing of specimens within the basic evolutionary sequence. This is the only part of the test which remains unaffected by ecological conditions, since it alone develops within the protective protoplasm of the microspheric generation. Henson (1948: 71), on the basis of faunas from the Middle East, was the first to propose that the majority of populations belonged 'to a single "plexus of descent" within which we have been able to recognise certain morphological "species" and "varieties" . . .'. However, the populations are not recognized by sharply-defined characteristics and can be isolated only when considering statistical analysis of dimensions and other characters. As Henson and most later workers have found, this causes difficulties in the determination of the lower and upper limits of each 'species' and 'variety'. Hofker formulated the most extreme theory and proposed that the genus is best regarded as being monospecific; this view we uphold. The synonymy provided here

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- Fig. 3 *Arenobulimina anglica* Cushman. P 49989. Side view. Middle Cenomanian Zone 10, Barrington, Cambridgeshire. $\times 24$.
- Fig. 4 *Arenobulimina advena* (Cushman). P 49990. Side view. Lower Cenomanian Zone 8, Barrington, Cambridgeshire. $\times 23$.
- Fig. 5 *Arenobulimina frankei* Cushman. P 49944. Side view. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 43$. (See also Pl. 1, fig. 1.)
- Fig. 6 *Flourensina mariae* sp. nov. P 49991. Side view. Holotype, Middle Cenomanian Zone 12, Buckland Newton, Dorset. $\times 23$.
- Fig. 7 *Eggerellina mariae* ten Dam. P 49993. Side view. Upper Albian Zone 6, Bed XIII, East Wear Bay, Folkestone, Kent. $\times 51$.
- Fig. 8 *Plectina mariae* (Franke). P 49994. Side view. Lower Cenomanian Zone 8, Barrington, Cambridgeshire. $\times 47$.
- Fig. 9 *Plectina cenomana* sp. nov. P 49995. Side view. **Holotype**, Upper Cenomanian Zone 13, Buckland Newton, Dorset. $\times 49$.
- Fig. 10 *Gaudryina austriana* Cushman. P 49996. Side view, Upper Cenomanian Zone 13, Buckland Newton, Dorset. $\times 45$.
- Fig. 11 *Guembeltria harrisi* Tappan. P 49997. Side view. Upper Albian Zone 6A, Cheriton, Folkestone, Kent. $\times 224$.
- Fig. 12 *Pseudotextulariella cretosa* (Cushman). P 49998. Side view. Middle Cenomanian Zone 10, Beachy Head, Eastbourne, Sussex. $\times 30$.
- Fig. 13 *Citharinella laffittei* Marie. P 49999. Side view. Upper Albian Zone 6A, Cheriton, Folkestone, Kent. $\times 12$.
- Fig. 14 *Vaginulina mediocarinata* ten Dam. P 50000. Side view. Upper Albian Zone 5, Bed XI, Copt Point, Folkestone, Kent. $\times 12$.
- Fig. 15 *Tritaxia pyramidata* Reuss. P 50001. Side view. Lower Cenomanian Zone 8, Barrington, Cambridgeshire. $\times 45$.
- Fig. 16 *Hedbergella washitensis* (Carsey). P 50002. Dorsal view. Middle Cenomanian Zone 11(ii), Orbirhynchia mantelliana band, Ackers Steps, Dover, Kent. $\times 48$.
- Fig. 17 *Heterohelix moremani* (Cushman). P 50003. Side view. Upper Albian Zone 6A, Cheriton, Folkestone, Kent. $\times 98$.
- Fig. 18 *Rotalipora cushmani* (Morrow). Specimen lost by authors. Ventral view. Middle Cenomanian Zone 10/11(i), Cenomanian Sands, Bovey Lane Sandpit, Beer, near Seaton, Devon. Glauconitic cast extracted from the calcareous sandstone with dilute acid. $\times 30$. (See also Pl. 4, figs 7-9.)
- Figs 19, 20 *Globigerinelloides bentonensis* (Morrow). Fig. 19, P 50004. Side view. Upper Albian Zone 6, Gault immediately below the Cambridge Greensand, Arlesley, Cambridgeshire - topotype level of *G. caseyi* (Bolli, Loeblich & Tappan). $\times 109$. Fig. 20, P 50005. Peripheral view. Middle Cenomanian Greenhorn Formation, western interior, U.S.A. - supplied by D. Eicher. $\times 117$. (See also Pl. 1, fig. 11.)

only covers those references that relate to the British specimens. In all previous accounts specimens have been referred to the species *Orbitolina concava* (Lamarck).

The form groups of Hofker are distributed as follows:

Form group I	U. Barremian – U. Aptian
Form group II	U. Aptian – L. Albian
Form group III.	L. Albian – U. Albian
Form group IV.	U. Albian – U. Cenomanian
Form group V	U. Cenomanian

As groups III–V are found elsewhere in the stratigraphic interval under consideration a short description of each (based mainly on Hofker's work) is given here. These demonstrate, as will be shown in detail later, that the British specimens from the Upper Greensand are completely contained within group IV.

Form group III. Proloculus with flat, sometimes concave, distal wall; well-developed epiembryonic chambers with an increasing number of partitions which seldom reach the wall of the proloculus.

Form group IV. Proloculus very close in appearance to a rounded triangle; epiembryonic chambers complex and subdivided into small, interconnected cellules; height of the cellule layer generally about half the height of the deuteroconch.

Form group V. Proloculus nearly spherical or arched; outer wall of deuteroconch radial, causing the embryonic apparatus to be more or less globular.

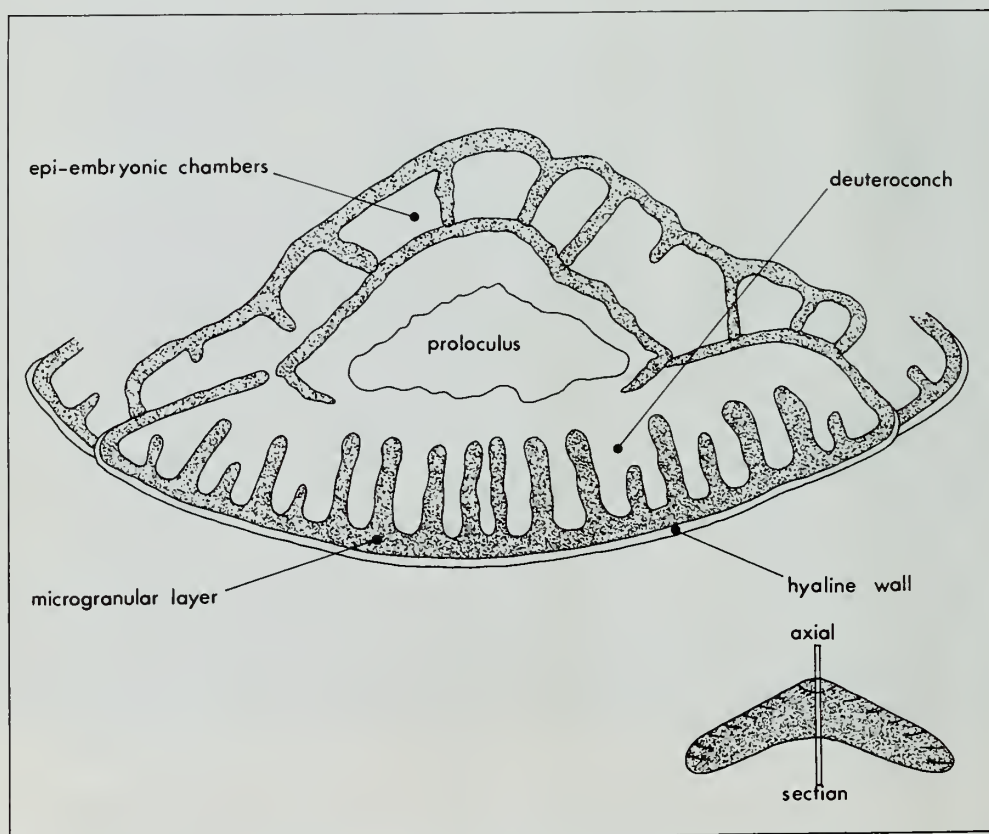


Fig. 4 Megalospheric embryonic apparatus of *Orbitolina lenticularis* (Blumenbach). Diagram built up from serial sections through a single test. ($\times 150$.)

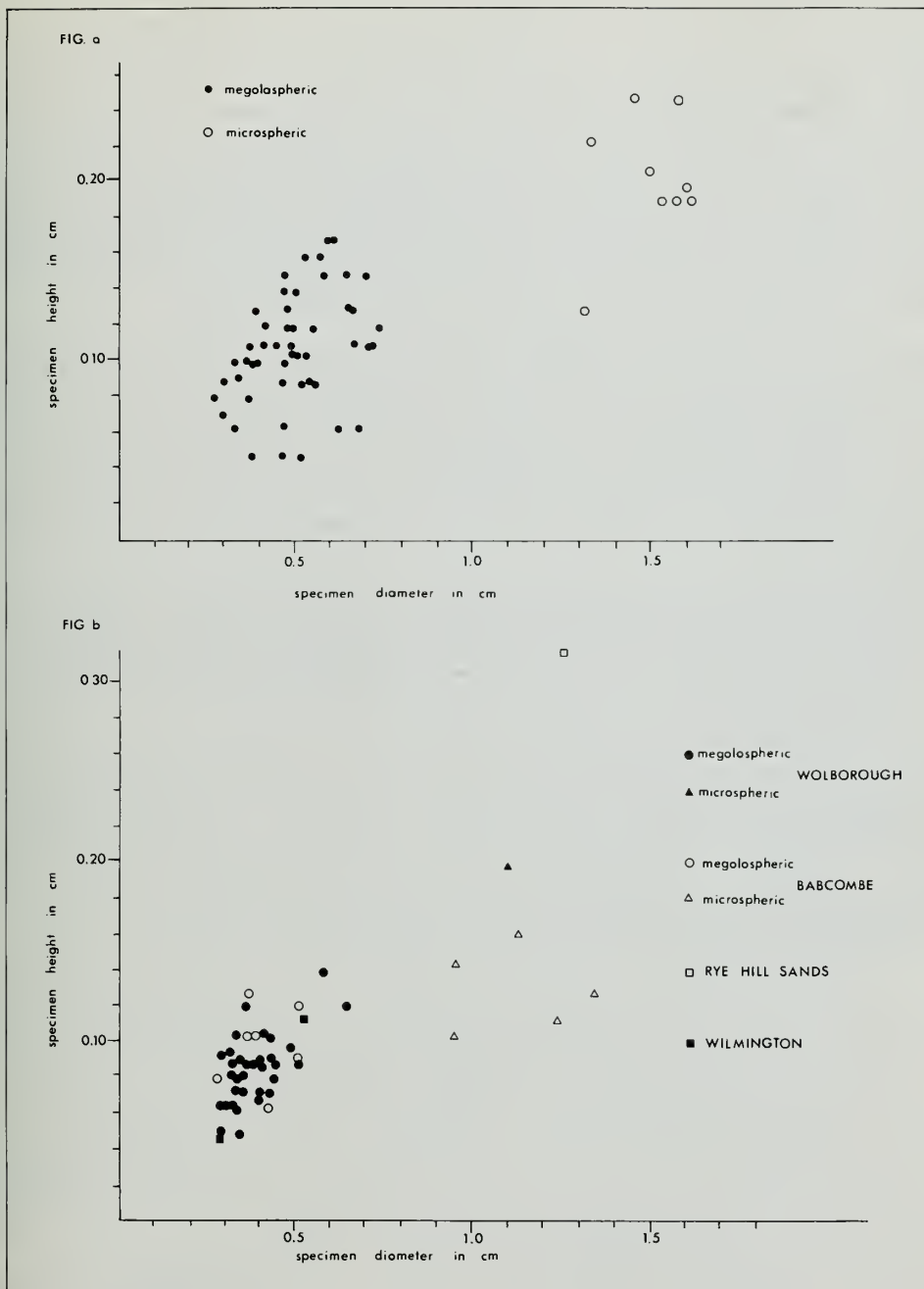


Fig. 5 Specimen height/width plots of representative populations of *O. lenticularis* (Blumenbach), (a) from Ballon, Sarthe, France, and (b) from various named localities in south-west England.

Form group IV is characterized by the species *O. concava* from the type locality of Ballon (Sarthe), France. Material from this area has been used in all comparative work and this is important in the subsequent stratigraphic analysis.

As the overall external appearance of the genus has been shown to be of little diagnostic value, the bulk of our work was done on oriented thin sections. Those which clearly showed the megalospheric embryonic apparatus provided the numerical data used in this work. The pattern of development of the embryonic apparatus was found to be almost identical to that figured by Hofker (1963 : fig. 20) as the typical form for the whole of group IV. The details of this are reproduced in diagrammatic form in Fig. 4. Using the serial sections it has been possible to establish that this form of embryonic apparatus is the only one represented in the typical Lower Cenomanian material from Ballon, and the Upper Greensand material from south-west England. It is hoped that the following data may establish that the populations in northern France and southern England were essentially synchronous, and can be used as such in any stratigraphical reinterpretation. Two comparative techniques have been used with some success.

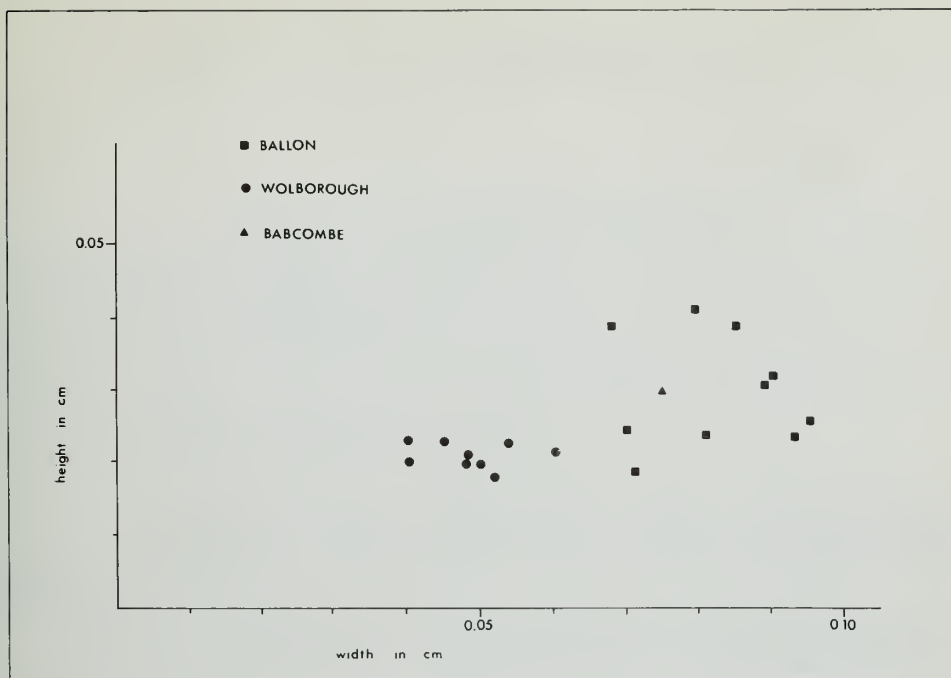
i. Height/width ratios. While outer dimensions have proved to be of little use for taxonomic work they can be used for the comparison of two populations within one taxon. The results of this investigation are plotted in Fig. 5. The measurements immediately separate the two generations. In the Ballon assemblage of megalospheric forms there is a wider range of size variation than in those from south-west England, although the main concentration of readings from the two areas fall very close to one another. While every attempt was made to obtain perfect axial sections, this was not always achieved, and the resulting inaccuracy could account for any discrepancies.

The microspheric population from Ballon falls into a moderately restricted area of the field. The single reading at its lower margin is probably of an immature specimen. However, in the specimens from south-west England there is a tremendous range of variation between specimens from different localities. The value recorded for the single microspheric specimen from Wolborough (Devon) is nearest to the concentration recorded from Ballon, and this would be expected since the two environments would appear, on sedimentological grounds, to be very similar. The plots for the specimens from Babcombe, which generally are much flatter in appearance than those from Ballon, fall within a restricted area. However, accurate measurement of the rather decomposed specimens from Babcombe is difficult. The single specimen from the Warminster Greensand is completely unlike any other specimen recorded in this present work and the difference is probably ecophenotypic.

The data suggest that the smaller megalospheric forms are less affected by the environment than the larger microspheric ones. This may explain the comparative closeness of the two megalospheric populations and yet the wide separation of the microspheric ones.

ii. Measurements of the megalospheric embryonic apparatus. The height and width of the megalospheric embryonic apparatus (Fig. 6), when seen in axial section, have provided a second method of comparison of the two populations. In this case there is much less agreement between the two groups. There is a very wide scatter in the specimens from Ballon, and this great variation in the size and form of the embryonic apparatus was also noted by Hofker, who gave an indication of it in some of his figures. This wider variation corresponds very well with that in the overall dimensions of the same specimens. In the case of Wolborough specimens, where the overall dimensions fell within closer limits, there is more evidence of concentration. An exception to this is the single measured specimen from Babcombe where the values fit closely with the specimens from Ballon. It seems that although the populations from Ballon and Wolborough can be compared fairly closely, there are variations probably produced by differences of environment.

The environmental relationships of *Orbitolina* have been discussed by Rat (1959) and Douglass (1960). The genus occurs in most facies, although it is generally associated with clastic sediments. Douglass concluded that in most cases the evidence indicated normal salinity, in a shallow-water, marine environment. The most limiting factor was temperature, the majority of occurrences being tropical or subtropical. The occurrences in south-west England are from the highest



latitude recorded by Douglass (1960 : fig. 1), even allowing for continental movements. However, the fauna from this area is sparse, even when compared with that of northern France, and it is interesting that *Orbitolina* has not been found in south-east England. In this case the controlling factor appears to be lithofacies or depth, rather than temperature.

The *O. lenticularis* populations of south-west England are thought to belong to the same faunal community as those of the type Lower Cenomanian of the Sarthe. The occurrence of this species in the Upper Greensand of south-west England is indicative of a Lower Cenomanian age for these sediments. This statement will be expanded more fully in the stratigraphic analysis.

RANGE. Lower Cenomanian (*Mantelliceras mantelli* Zone), Zones 7–9.

Family **PAVONITINIDAE** Loeblich & Tappan 1961Subfamily **PFENDERININAE** Smout & Sugden 1962Genus *PSEUDOTEXTULARIELLA* Barnard in Barnard & Banner 1953

TYPE SPECIES. *Textulariella cretosa* Cushman 1932.

Pseudotextulariella cretosa (Cushman 1932)

(Plate 2, fig. 12)

1932 *Textulariella cretosa* Cushman: 97; pl. 11, figs 17-19.

1937b *Textulariella cretosa* Cushman; Cushman: 61; pl. 6, figs 26–28.

1948 *Textulariella cretosa* Cushman; Williams-Mitchell: 97; pl. 8, fig. 1.

1953 *Pseudotextulariella cretosa* (Cushman) Barnard in Barnard & Banner: 198; text-figs 6b-i.

1963 *Pseudotextulariella cretosa* (Cushman); Barnard: 48; pl. 7, figs 1-6; text-figs 6a-d, 7a-f, 8a-c.

1972 *Pseudotextulariella cretosa* (Cushman); Gawor-Biedowa: 34-35; pl. 3, fig. 4a-b.

REMARKS. This large, highly distinctive species occurs in large numbers in the lower levels of the Cenomanian. Barnard (1963: text-fig. 9) indicated, quite erroneously, that this species first appears in the uppermost levels of the Albian.

RANGE. Cenomanian Zones 9–12.

Suborder MILIOLINA Delage & Hérouard 1896

Superfamily MILIOLACEA Ehrenberg 1838b

Family NUBECULARIIDAE Jones 1875

Subfamily SPIROLOCULININAE Wiesner 1920

Genus *SPIROLOCULINA* d'Orbigny 1826

TYPE SPECIES. *Spiroloculina depressa* Cushman 1917.

Spiroloculina papyracea Burrows, Sherborn & Bailey 1890

(Plate 1, fig. 6)

1890 *Spiroloculina papyracea* Burrows, Sherborn & Bailey: 551; pl. 8, fig. 1.

1950 *Spiroloculina papyracea* Burrows, Sherborn & Bailey; ten Dam: 18; pl. 1, fig. 19.

1967 *Spiroloculina papyracea* Burrows, Sherborn & Bailey; Fuchs: 277; pl. 5, fig. 8.

REMARKS. Although the majority of workers have referred this species to the genus *Spiroloculina*, there is some doubt about this attribution. Specimens show a minute, early, quinqueloculine growth form, which indicates a close relationship to the genus *Massilina* Schlumberger. In the present account, however, *Spiroloculina* is retained.

S. papyracea was initially described from the Albian, and all other records of the species refer to this level. Reuss (1854) also described as *S. cretacea* a species which is very similar to Burrows, Sherborn & Bailey's *S. papyracea*. However, *S. cretacea* was initially described from the Turonian to Coniacian of the Gosau area (Austria), and the subsequent references to it come only from the Upper Cretaceous. Franke (1928) referred Cenomanian specimens to *S. cretacea* and it is possible that the two species will prove synonymous. The reason for retaining *S. papyracea* is that the authors' specimens compare well with type-level material, and the specimens from the Cenomanian are identical with those from the Albian.

RANGE. This species is encountered between the Upper Albian Zone 5 and the upper levels of Cenomanian Zone 11(i), although rare specimens have been found in Albian Zone 4a and Cenomanian Zones 11(ii), 13, and 14(i–iia) (Plenus Marls Beds 1–3).

Subfamily NODOBACULARIINAE Cushman 1927

Genus *NODOBACULARIA* Rhumbler 1895

TYPE SPECIES. *Nubecularia tibia* Jones & Parker 1860.

Nodobacularia nodulosa (Chapman 1891)

(Plate 1, fig. 5)

1891 *Nubecularia nodulosa* Chapman: 573; pl. 9, fig. 2.

1948a *Nubeculina nodulosa* (Chapman) ten Dam: 177.

1949 *Pseudonubeculina nodulosa* (Chapman) Bartenstein & Brand: 670; figs 3–5.

1950 *Pseudonubeculina nodulosa* (Chapman); ten Dam: 18; pl. 1, fig. 20.

1951 *Pseudonubeculina nodulosa* (Chapman); Bartenstein & Brand: 278; pl. 4, figs 82–84.

1965 *Pseudonubeculina nodulosa* (Chapman); Neagu: 10; pl. 2, figs 25, 26.

1967 *Nodobacularia nodulosa* (Chapman) Fuchs: 278; pl. 5, figs 1, 2.

REMARKS. We have followed Fuchs (1967) in placing this distinctive species in the genus *Nodobacularia* (after Loeblich & Tappan 1964, *Treatise*).

RANGE. Albian Zones 4 and 5a, with rare and scattered specimens being found in Zone 6.

Family **MILIOLIDAE** Ehrenberg 1838b
Subfamily **QUINQUELOCULININAE** Cushman 1917
Genus **QUINQUELOCULINA** d'Orbigny 1826

TYPE SPECIES. *Serpula seminulum* Linné 1758.

Quinqueloculina antiqua (Franke 1928)
(Plate 1, figs 7, 8)

- 1891 *Miliolina venusta* Karrer; Chapman: 9; pl. 9, figs 5, 6.
1891 *Miliolina Ferussacii* (d'Orbigny); Chapman: 10; pl. 9, fig. 8.
1891 *Miliolina tricarinata* (d'Orbigny); Chapman: 10; pl. 9, fig. 9.
1928 *Miliolina (Quinqueloculina) antiqua* Franke: 126; pl. 11, fig. 26.
1950 *Quinqueloculina antiqua* (Franke) ten Dam: 17; pl. 1, fig. 18.
1954 *Quinqueloculina antiqua* (Franke); Vasilenko: 33–34; pl. 6, figs 8a, b, w, 9a, b, w.
1957 *Quinqueloculina kochi* (Reuss); Hofker: 436, text-fig. 494.
1965 *Pseudosigmoilina antiqua* (Franke) Bartenstein: 351–2.
1967 *Quinqueloculina antiqua* (Franke); Fuchs: 279; pl. 5, fig. 5a–b.
1972 *Quinqueloculina antiqua* (Franke); Gawor-Biedowa: 35–36; pl. 3, fig. 6a–c.

REMARKS. According to Chapman (1891) the sharp-edged form (*M. venusta*) is superseded upwards by the round-edged form (*M. ferussacii*). In this species the angles of the test become more rounded as growth proceeds.

RANGE. Small forms appear in Albian Zone 2, although significant numbers are found only above Zone 4; it is abundant in the Cenomanian up to and including Zone 9, although small forms have been recorded in the remainder of the Cenomanian.

Suborder **ROTALIINA** Delage & Hérouard 1896
Superfamily **NODOSARIACEA** Ehrenberg 1838a
Family **NODOSARIIDAE** Ehrenberg 1838a
Subfamily **NODOSARIINAE** Ehrenberg 1838a
Genus **CITHARINELLA** Marie 1938

TYPE SPECIES. *Flabellina karreri* Berthelin 1880.

Citharinella laffittei Marie 1938
(Plate 2, fig. 13)

- 1938 *Citharinella laffittei* Marie: 101; pl. 8, fig. 3.

REMARKS. This very long, slender species has rarely been found complete, but the characteristic ornament allows an identification of even the smallest fragments.

RANGE. Only common to Zone 6a, although the full range is from Albian Zone 5a to Cenomanian Zone 8.

Citharinella pinnaeformis (Chapman 1894)
(Plate 1, fig. 9)

- 1894 *Frondicularia pinnaeformis* Chapman: 185; pl. 3, figs 9–11.
1938 *Citharinella pinnaeformis* (Chapman) Marie: 100; pl. 7, figs 7–9; pl. 8, figs 4–6.
1950 *Citharinella pinnaeformis* (Chapman); ten Dam: 38–39.

REMARKS. This species is an important zonal indicator in the Upper Albian (Zone 5), where it can be used with *A. chapmani* for correlation.

RANGE. Albian Zones 4a–5a; the very rare specimens that are found in Zone 6 are probably derived.

Genus *VAGINULINA* d'Orbigny 1826

TYPE SPECIES. *Nautilus legumen* Linné 1758.

Vaginulina mediocarinata ten Dam 1950
(Plate 2, fig. 14)

1894 *Vaginulina strigillata* Chapman: 423; pl. 8, figs 3–4 (*non* Reuss).

1950 *Vaginulina mediocarinata* ten Dam: 36–37; pl. 3, fig. 3.

REMARKS. Although this species has not been found outside the Gault Clay facies, it is nevertheless useful in south-east England where it occurs typically in the Upper Albian.

RANGE. Albian Zones 4a–6.

Superfamily **GLOBIGERINACEA** Carpenter, Parker & Jones 1862

Family **HETEROHELICIDAE** Cushman 1927

Subfamily **GUEMBELITRIINAE** Montanaro-Gallitelli 1957

Genus *GUEMBELITRIA* Cushman 1933

TYPE SPECIES. *Guembelitra cretacea* Cushman 1933.

Guembelitra harrisi Tappan 1940
(Plate 2, fig. 11)

1940 *Guembelitra harrisi* Tappan: 115; pl. 19, fig. 2a–b.

1967 *Guembelitra harrisi* Tappan; Pessagno: 258; pl. 48, figs 12, 13.

1970 *Guembelitra harrisi* Tappan; Eicher & Worstell: 296; pl. 8, figs 1–2.

REMARKS. Bandy (1967) records only two species of *Guembelitra* – *G. cretacea* Cushman from the Maastrichtian and *G. harrisi* from the Albian. *G. harrisi*, the larger species, has a lower aperture, is less rapidly flaring and comparatively narrow. Bandy (1967) derives *G. cretacea* from *Heterohelix globulosa* (Ehrenberg) and it is possible that, in a similar way, *G. harrisi* is a triserial derivative of *H. moremani* (Cushman). However, it is more likely that *G. cretacea* is a continuation of the *G. harrisi* lineage, as the specimens found in the Upper Cenomanian and Lower Turonian are very similar to both *harrisi* and *cretacea*. Keller (1935) describes a species *Guembelitra cenomana* (1935: 547; pl. 2, figs 13, 14) which is very close to *G. harrisi* Tappan.

G. harrisi differs from the *G. cenomana* of Gawor-Biedowa (1972: 61) in the sudden increase in size of the chambers with growth, but her figure (1972: pl. 5, fig. 4) seems to fall within the allowable range for *G. harrisi*. We feel that the two species are probably synonymous. If so the name *cenomana* should presumably take priority, but we leave this matter pending further investigation.

RANGE. Appearing in the Middle Albian, this species is common in the Upper Albian, Cenomanian and Lower Turonian.

Subfamily **HETEROHELICINAE** Cushman 1927

Genus *HETEROHELIX* Ehrenberg 1843

TYPE SPECIES. *Spiroplecta americana* Ehrenberg 1844.

Heterohelix moremani (Cushman 1938)
(Plate 2, fig. 17)

1938 *Guembelina moremani* Cushman: 10, pl. 2, figs 1–3.

1940 *Guembelina washitensis* Tappan: 115; pl. 19, fig. 1.

1946 *Guembelina moremani* Cushman; Cushman: 103–104; pl. 46, figs 15, 16, not 17.

1962 *Heterohelix* sp. Ayala-Castanares: 11; pl. 1, fig. 1a–c; pl. 6, fig. 1a–c.

1967 *Heterohelix moremani* (Cushman) Pessagno: 260–261; pl. 48, figs 10–11; pl. 89, figs 1–2.

REMARKS. This species is very similar to *H. washitensis*, initially described from the Grayson Formation of Texas. The total range of *H. washitensis* was given by Tappan as Aptian to

Cenomanian. Tappan (1940) also noted the latter's similarity to *H. moremani*, but claimed that her species was smaller, possessed more horizontal sutures and had more globular chambers. The latter feature is not thought significant, as within a single population of *H. moremani* from the Upper Cenomanian all the extremes from nearly straight-sided to globose chambers are seen.

Pessagno (1967) noted that larger, gerontic specimens of *H. moremani*, such as the holotype, tend to show a more highly arched aperture, whereas the smaller specimens (which he figured on his pl. 48, figs 10–11) show low arched apertures. This, he claims, makes Tappan's differentiation, on the basis of the low aperture and smaller size, invalid. Therefore *H. washitensis* appears to be a junior synonym of *H. moremani*.

Bandy (1967) regards the two species as distinct and shows (fig. 11) that they follow each other in stratigraphic order. He also suggests they may be a dimorphic pair although, as he points out, this is unlikely as they have slightly different overall ranges. Bandy was prepared to accept *H. washitensis* as the ancestral form of *H. moremani*, and while this is the view held by ourselves, specific separation of the two forms is impossible.

RANGE. Middle Albian to Lower Turonian, although in the latter stage the number of individuals is greatly reduced.

Family **PLANOMALINIDAE** Bolli, Loeblich & Tappan 1957

Genus **GLOBIGERINELLOIDES** Cushman & ten Dam 1948

TYPE SPECIES. *Globigerinelloides algeriana* Cushman & ten Dam 1948.

Globigerinelloides bentonensis (Morrow 1934)

(Plate 1, fig. 11; Plate 2, figs 19, 20)

- non 1927 *Anomalina eaglefordensis* Moreman: 99; pl. 16, fig. 9.
- 1934 *Anomalina bentonensis* Morrow: 201; pl. 30, fig. 4a–b.
- 1940 *Anomalina bentonensis* Morrow; Cushman: 28; pl. 5, fig. 3a–b.
- non 1940 *Planulina eaglefordensis* (Moreman) Cushman: 32; pl. 6, figs 4, 5.
- 1946 *Anomalina bentonensis* Morrow; Cushman: 154; pl. 63, fig. 7a–b.
- non 1946 *Planulina eaglefordensis* (Moreman); Cushman: 156; pl. 64, figs 8a–c, 9.
- 1957 *Planomalina caseyi* Bolli, Loeblich & Tappan: 24; pl. 1, figs 4a–5b.
- 1961b *Globigerinelloides bentonensis* (Morrow) Loeblich & Tappan: 267; pl. 2, figs 8–10.
- non 1961b *Globigerinelloides eaglefordensis* (Moreman) Loeblich & Tappan: 268; pl. 2, figs 3a–7b.
- non 1962 *Globigerinelloides eaglefordensis* (Moreman); Ayala-Castanares: 15–16; pl. 1, fig. 2a–c; pl. 6, figs 2a–b, 3a–b.
- non 1964 *Globigerinelloides eaglefordensis* (Moreman); Loeblich & Tappan: C657–658, fig. 526, 7a–b.
- 1964 *Globigerinelloides caseyi* (Bolli, Loeblich & Tappan) Low: 122–123.
- 1965 *Globigerinelloides bentonensis* (Morrow); Eicher: 904; pl. 106, fig. 10.
- 1966 *Planomalina* (*Globigerinelloides*) *caseyi* (Bolli, Loeblich & Tappan); Salaj & Samuel: 161; pl. 6, fig. 1a–b.
- 1967 *Globigerinelloides bentonensis* (Morrow); Pessagno: 275; pl. 76, figs 10–11.
- 1967 *Globigerinelloides caseyi* (Bolli, Loeblich & Tappan); Pessagno: 276; pl. 49, figs 2–5.
- 1969a *Globigerinelloides caseyi* (Bolli, Loeblich & Tappan); Douglas: 161; pl. 5, fig. 9.
- 1970 *Globigerinelloides bentonensis* (Morrow); Eicher & Worstell: 297; pl. 8, figs 17a–b, 19a–b; pl. 9, figs 3a–b.
- 1970 *Globigerinelloides caseyi* (Bolli, Loeblich & Tappan); Eicher & Worstell: 297–298; pl. 8, figs 11, 15a–b, 16.
- 1972 *Globigerinelloides bentonensis* (Morrow); Gawor-Biedowa: 63–64; pl. 6, fig. 7a–c.

REMARKS. Initially described as an *Anomalina*, the planktonic nature of this species was not recognized for many years. Loeblich & Tappan (1961b), after inspecting the holotype, concluded that Morrow's species was better placed in the genus *Globigerinelloides*. In the same publication they placed *Anomalina eaglefordensis* in the same genus, recording that it differed from *G. bentonensis* in being smaller, less inflated and more evolute. *Planomalina caseyi*, originally described from the Gault Clay of England, was regarded as a junior synonym of *G. eaglefordensis*.

Pessagno (1967) confirmed Low's (1964) belief that *A. eaglefordensis* was a benthonic species and all the planktonic individuals referred to it ought to be placed in *G. caseyi*. However, many

authors have noted the resemblance of *G. caseyi* (or *G. eaglefordensis*) to *G. bentonensis*. Low (1964) thought there were slight differences in the tightness of the coil and in the number of chambers in the final whorl, and kept the species separate, while Eicher (1965) considered them almost inseparable. In a more recent account Eicher & Worstell (1970) retain the two species while admitting the difficulties in so doing. The main differences recorded are the overall size, tightness of coiling, degree of inflation, and the rate of increase in size of the chambers. The present authors regard most of these variations as correlated with an increase in overall size. Eicher & Worstell's discussion of the distribution indicates that there is a possibility of ecological control. They report that specimens of *G. caseyi* occur in their upper planktonic zone while larger individuals of *G. bentonensis* are seen in the benthonic zone. Small specimens of both species occur in the benthonic zone and it is at this level that they found the greatest difficulty in distinguishing between them.

The initial concept of *G. caseyi* as a viable species is in doubt. Loeblich & Tappan (1961b) report that *G. eaglefordensis* (*G. caseyi*) has a diameter range of 0.15–0.31 mm, while *G. bentonensis* is generally larger (0.21–0.41 mm). This alone is no justification for the separation of the two species, but when all features are considered a case can be made out. In the Upper Gault Clay (Upper Albian) of England specimens of *G. caseyi* are usually small and would fall well within the range for the species indicated by Loeblich & Tappan. However, at certain levels within this clay sequence very large 'atypical' specimens are found. In all other ways these are identical with the smaller, more 'typical' members of the species. It would seem, therefore, that there is some form of environmental control on the overall size of the specimens.

Topotype specimens of *G. bentonensis* have been compared with topotype specimens of *G. caseyi* from Arlesey, England. Scanning electron photomicrographs of the two species appear almost identical and, even allowing for their stratigraphic separation, can only be regarded as synonymous. One feature shown by the specimens of *G. bentonensis* is the non-equatorial aperture. As all previous authors have described this species as possessing an equatorial aperture we assume that this variation is a feature peculiar to some of the specimens from the topotype locality and horizon.

Bandy (1967) recognizes *G. bentonensis* from the Cenomanian, as being derived from *G. escheri* Kaufman at the Albian/Cenomanian boundary. He also states that *G. caseyi* is a junior subjective synonym of *G. escheri*. Since *G. caseyi* and *G. bentonensis* are shown here to be synonymous, *G. escheri* is the valid name for the whole group. However, Bandy's figure (1967: fig. 5) of *G. caseyi* is closer to that of *G. bentonensis* than it is to that of *G. escheri*, and it is more likely that *G. bentonensis* and *G. escheri* are distinct.

In England *G. bentonensis* appears in the Upper Albian with other planktonic species. At this level it is already completely differentiated from species of the genus *Hedbergella* Bronnimann & Brown, and Bandy's (1967) suggestion that it evolved from *G. blowi* (Bolli) in the Aptian is accepted.

RANGE. Upper Albian to Lower Cenomanian (in England), although rare specimens have been found throughout the whole Cenomanian sequence up to and including the Plenus Marls. Above this level specimens of *Globigerinelloides* would appear to be referable to *G. ehrenbergi* (Barr).

Family SCHACKOINIDAE Pokorný 1958

Genus SCHACKOINA Thalmann 1932

TYPE SPECIES. *Siderolina cenomana* Schacko 1897.

Schackoina cenomana (Schacko 1897)

(Plate 1, fig. 10)

1897 *Siderolina cenomana* Schacko: 166; pl. 4, figs 3–5.

1900 *Siderolina cenomana* Schacko; Egger: 174; pl. 21, fig. 42.

1928 *Siderolina cenomana* Schacko; Franke: 183; pl. 18, fig. 11a–c.

1930 *Hantkenina cenomana* (Schacko) Cushman & Wickenden: 40; pl. 6, figs 4–6.

1932 *Hantkenina* (*Schackoina*) *cenomana* (Schacko) Thalmann: 288.

- 1947 *Schackoina gandolfi* Reichel: 397, text-figs 3a–g, 6(3), 7(3), 8a, 10(1, 3, 4); pl. 8, fig. 1.
 1951 *Schackoina cenomana* (Schacko); Noth: 74; pl. 5, figs 9–10.
 1952 *Hastigerinoides rohri* Brönnimann: 55; text-fig. 29a–f; pl. 1, figs 8–9.
 1954 *Schackoina gandolfi* Reichel; Aurouze & de Klasz: 99, text-fig. 1c.
 1954 *Schackoina* sp. du groupe *cenomana* (Schacko); Aurouze & de Klasz: pl. 6a.
 1955 *Schackoina cenomana* (Schacko); Montanaro-Gallitelli: 143–144.
 1957 *Schackoina cenomana* (Schacko); Bolli, Loeblich & Tappan: 26; pl. 2, figs 1–2.
 1959 *Schackoina gandolfi* Reichel; Bolli: 263; pl. 20, figs 12–18.
 1959 *Schackoina cenomana* (Schacko); Bykova, Vasilenko, Voloshinova, Miatliuk & Subbotina: 300; text-fig. 676.
 1959 *Schackoina cenomana* (Schacko); Orlov *et al.*: 300; text-fig. 676A–B.
 1961b *Schackoina cenomana* (Schacko); Loeblich & Tappan: 270–271; pl. 1, figs 2–7.
 1962 *Schackoina cenomana* (Schacko); Ayala-Castanares: 20–21; pl. 2, figs 2–3; pl. 7, fig. 3a–b; pl. 8, fig. 1a–c.
 1964 *Schackoina cenomana* (Schacko); Loeblich & Tappan: C658, fig. 526, 8a–c, 9.
 1966 *Schackoina cenomana* (Schacko); Salaj & Samuel: 165–166; pl. 7, fig. 8a–c.
 1967 *Schackoina cenomana* (Schacko); Pessagno: 279; pl. 48, fig. 6.
 1969 *Schackoina cenomana* (Schacko); Douglas: 162–163; pl. 6, fig. 5.
 1969 *Schackoina cenomana* (Schacko); Scheibnerova: 57; pl. 7, figs 5–7.
 1970 *Schackoina cenomana* (Schacko); Eicher & Worstell: 298; pl. 9, figs 1, 2, 4.
 1972 *Schackoina cenomana cenomana* (Schacko); Gawor-Biedowa: 64–65; pl. 6, fig. 1.

REMARKS. This species appears to be very rare in the British sequences, although this may reflect the processing techniques used during the present work. All the samples from south-west England had to be crushed under water – a method that may well destroy all trace of this very fragile species. However, in south-east England, where the Chalk is softer (and the necessary processing therefore less forceful), it is still extremely rare.

It appears to be the only representative of the genus in the British Isles, so very little can be said of its origin or development. In Britain it is first seen in the Middle Cenomanian; elsewhere the species has been recorded throughout the Cenomanian.

RANGE. Upper Cenomanian Zones 13 and 14(i) (iia) (=Plenus Marls Beds 1–3), and Lower Turonian, although rare specimens have been found in Cenomanian Zones 10–12.

Family ROTALIPORIDAE Sigal 1958

Subfamily HEDBERGELLINAE Loeblich & Tappan 1961

Genus *HEDBERGELLA* Brönnimann & Brown 1958

TYPE SPECIES. *Anomalina lorneiana* d'Orbigny var. *trochoidea* Gandolfi 1942.

Hedbergella amabilis Loeblich & Tappan 1961

(Plate 3, figs 22, 23)

- 1927 *Globigerina cretacea* d'Orbigny; Moreman: 100; pl. 16, fig 14–15.
 1952 *Globigerina cretacea* d'Orbigny; Brönnimann: 14–16, text-fig. 3a–m.
 1961b *Hedbergella amabilis* Loeblich & Tappan: 274; pl. 3, figs 1–10.
 1961b *Clavihedbergella simplex* (Morrow); Loeblich & Tappan: 279–280; pl. 3, figs 11a–c, not figs 12–14.
 1962 *Clavihedbergella simplex* (Morrow); Ayala-Castanares: 25–26; pl. 4, figs 2a–c, 3a–c, not fig. 1a–c; pl. 5, fig. 1a–c.
 1963 *Hedbergella amabilis* Loeblich & Tappan; Renz, Luterbacher & Schneider: 1084; pl. 9, figs 4–6.
 1964 *Clavihedbergella simplex* (Morrow); Todd & Low: 403–404; pl. 1, fig. 1.
 1966 *Clavihedbergella amabilis* (Loeblich & Tappan) Salaj & Samuel: 173; pl. 10, fig. 3a–c.
 1967 *Hedbergella amabilis* Loeblich & Tappan; Pessagno: 281–282; pl. 52, figs 6–8.
 1969 *Hedbergella amabilis* Loeblich & Tappan; Douglas: 165; pl. 4, fig. 8.
 1970 *Hedbergella amabilis* Loeblich & Tappan; Eicher & Worstell: 300, 302; pl. 9, figs 12, 13a–c.

REMARKS. This species is very close in appearance to *Clavihedbergella simplex* (Morrow) and many authors have regarded the two as synonymous. However, recent accounts by Pessagno (1967) and Douglas (1969) indicate that they are distinct and have different ranges. Comparison of the type figures reveals that *H. amabilis* is larger than *C. simplex*, and lacks the radially elongated chambers



Plate 3

Figs 1-3 *Praeglobotruncana algeriana* Caron. P 50006. Dorsal, ventral and peripheral views. Lowermost Turonian, Marnes à *Terebratella carentonensis*, Mezières s'Ballon, Sarthe, France. $\times 53$.

characteristic of the latter, although the chambers of *H. amabilis* still must be described as sub-clavate. The topotype specimen of *H. amabilis* (Loeblich & Tappan 1961b: pl. 3, figs 1–10) shows a finely hispid test with a prominent apertural flap. The chambers are very slightly elongated, although this feature is over-emphasized by the very constricted sutures. *C. simplex* possesses a smooth surface with chambers that are very distinctly elongated. Loeblich & Tappan's paratypes of *H. amabilis* show great variation through a range which almost extends far enough to include *C. simplex*. Many authors think that the two species cannot be separated and regard the whole group as a single plexus. This may be the case, but because in England there occur representatives of *H. amabilis* only, this name is used here.

Many specimens of *H. amabilis* have almost rounded chambers and much less constricted sutures, thus showing a tendency to approach *H. delrioensis* (Carsey). *H. planispira* (Tappan) possesses the low spire characteristic of *H. amabilis*, but is much smaller.

In England *H. amabilis* appears sporadically throughout the Cenomanian and shows no close relationship with any other species. The true *C. simplex* has not been recorded. There is no link with the probably ancestral *H. planispira*, distinctions between the two species appearing suddenly at the Albion/Cenomanian boundary.

RANGE. Cenomanian Zones 7–14; also present in the Turonian in reduced numbers.

Hedbergella brittonensis Loeblich & Tappan 1961

(Plate 4, figs 13–15)

1934 *Globigerina cretacea* d'Orbigny; Morrow: 198; pl. 30, figs 7, 8, 10a–b.

1955 *Globigerina* cf. *G. cretacea* d'Orbigny; Applin: 196; pl. 48, figs 23–24.

1955 *Globigerina* sp. Küpper: 117; pl. 18, fig. 9a–c.

1961b *Hedbergella brittonensis* Loeblich & Tappan: 274–275; pl. 4, figs 1–8.

1961b *Hedbergella portsdownensis* (Williams-Mitchell) Loeblich & Tappan: 277; pl. 5, fig. 3a–c.

1967 *Globigerina portsdownensis* Williams-Mitchell; Bandy: 8, text-fig. 3.

1967 *Hedbergella brittonensis* Loeblich & Tappan; Fuchs: 331; pl. 18, fig. 1a–c.

1969b *Hedbergella portsdownensis* (Williams-Mitchell); Eicher: 168, fig. 3.

1969 *Hedbergella portsdownensis* (Williams-Mitchell); Douglas & Rankin: 194–196, fig. 7.

1970 *Hedbergella portsdownensis* (Williams-Mitchell); Eicher & Worstell: 304; pl. 10, figs 1a–c, 2a–b.

1972 *Hedbergella brittonensis* Loeblich & Tappan; Gawor-Biedowa: 67–68; pl. 8, figs 1a–c, 2a–c.

REMARKS. This species was erected by Loeblich & Tappan (1961) to include some of the forms placed in '*Globigerina cretacea*' but which possess an elevated spire. The dimensions of the holotype certainly demonstrate the elevation of the spire and the type figures display this feature

Figs 4–6 *Praeglobotruncana hagni*/P. *algeriana* transitional form. P 50007. Dorsal, ventral and peripheral views. Lowermost Turonian Zone 14(iib), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. × 50.

Figs 7–9 *Globotruncana* cf. *indica* (Pessagno non Jacob & Sastry). P 50010. Dorsal, ventral and peripheral views. Lowermost Turonian Zone 14(iib), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. × 56.

Figs 10–12 *Praeglobotruncana hagni* Scheibnerova. P 50011. Dorsal, peripheral and ventral views. Lowermost Turonian, Marnes à *Terebratella carentonensis*, Mezières s'Ballon, Sarthe, France. Figs 4–5, × 51; Fig. 6, × 46.

Figs 13–15 *Rotalipora evoluta* Sigal. Fig. 13, P 50013, × 56; Figs 14–15, P 50014, × 45. Dorsal, ventral and peripheral views. Middle Cenomanian Zone 11(i), Beachy Head, near Eastbourne, Sussex.

Figs 16, 17 *Praeglobotruncana* cf. *helvetica* (Bolli). P 50015. Ventral and peripheral views. Lowermost Turonian Zone 14(iib), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. × 45.

Figs 18–20 *Hedbergella infracretacea* (Glaessner). P 50016. Dorsal, ventral and peripheral views. Upper Albion Zone 6, Bed XIII, Cheriton, Folkestone, Kent. × 62.

Fig. 21 '*Hedbergella cretacea* (d'Orbigny).' P 50017. Peripheral view. Upper Cenomanian Zone 14(iiia), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. × 54.

Figs 22, 23 *Hedbergella amabilis* Loeblich & Tappan. P 50018–9. Dorsal and ventral views. Upper Cenomanian Zone 13, Maiden Newton, Dorset. Fig. 22, × 69; Fig. 23, × 96.

clearly. However, in the same publication Loeblich & Tappan refer closely similar individuals to the species *H. portdownensis*. Although they claim that this species has a low spire, they illustrate (1961 : pl. 5, fig. 3a-c) a specimen with a spire equal to, if not higher than, that in some of the figures of *H. brittonensis*.

This would appear to invalidate *H. brittonensis* on grounds of priority, but an added complication has arisen. Loeblich & Tappan (1961) do not mention the type specimen of *H. portdownensis* and only figure hypotypes from the Cenomanian of Germany. Eicher & Worstell (1970) were misled by this inclusion of German specimens into assuming that the species had been described originally from the Cenomanian of Germany.

The holotype (P 38283) of *H. portdownensis* in the British Museum (Natural History), London, has been inspected and the original description of the species found incorrect. Williams-Mitchell's (1948) description refers to specimens commonly seen in the Upper Cenomanian of England, in which the final chamber typically overhangs the umbilicus. Unfortunately the holotype does not show this feature and would be better placed in *H. delrioensis*. The spire certainly is not elevated enough to warrant specific separation and it is not at all like that illustrated by Loeblich & Tappan (1961) as typical of the species. If *H. portdownensis* is a junior synonym of *H. delrioensis*, then *H. brittonensis* in our sense becomes the valid name for those high-spired Cenomanian forms ascribed to *H. delrioensis*. However, there is, in any population, a full range from the lower-spired, typical *H. delrioensis* to the high-spired, typical *H. brittonensis*, and not even a mathematical approach permits their satisfactory separation. The two names are used here to refer to the end members of the plexus. However, recent communications with workers in the U.S.A. show that the type specimens of *H. brittonensis* may not be as high-spired as the type descriptions and figures suggest. If this proves correct there will be no satisfactory name for the species. Nevertheless, until the holotypes can be examined the name *H. brittonensis* is retained.

Williams-Mitchell (1948) confined *H. portdownensis* to the Cenomanian, and while we do not condone the practice of changing specific names at stratigraphic boundaries, *H. infracretacea* (Glaessner 1966) is used for the earlier Albian forms of the same plexus. The latter, although similar in external characteristics, is generally much smaller and usually displays a more overhanging final chamber.

RANGE. Mainly Cenomanian Zones 7-14(jia) (Plenus Marls Bed 3); some individuals have been encountered in the Lower Turonian.

'Hedbergella cretacea (d'Orbigny 1840)
(Plate 3, fig. 21)

A full synonymy has not been prepared as the individuals discussed here are not typical of d'Orbigny's species.

REMARKS. D'Orbigny's species has been cited by many authors for any planktonic foraminifer seen in rocks younger than the Lower Cretaceous. Brady (1884) even listed it as a Recent species. However, during the last decade there have been several attempts to rationalize our understanding of *Globigerina cretacea* d'Orbigny. Some of these have clarified, while others have confused the situation. While we do not intend to repeat these arguments, additional data relating to the origin of this species is presented.

Globigerina cretacea d'Orbigny was originally described in 1840 from the White Chalk of St Germain, near Paris. This bed is regarded as Lower Campanian in age. In 1960 Banner & Blow redescribed d'Orbigny's original specimens. They found only one phial of specimens from St Germain in the Musée d'Histoire Naturelle in Paris and selected the most complete specimen from the syntypic series as the lectotype (Banner & Blow 1960 : 8: pl. 7, fig. 1). The diagnosis they gave was very like that of d'Orbigny but differed in two respects. The lectotype was seen to possess two broadly spaced yet weakly developed keels, and it was assumed that these had not been seen by d'Orbigny. Other specimens in d'Orbigny's collection, appearing conspecific with the lectotype, possess well-preserved tegillae. These facts, in Banner & Blow's opinion, placed the species in the genus *Globotruncana* Cushman, which ranges from Coniacian? to Campanian.

Hofker (1961), unaware of Banner & Blow's work, cites Marie (1941) as recording only two planktonic foraminifera in the 'Craie Blanche' at Meudon (*Globigerina aspera* Ehrenberg and *Globigerina cretacea* d'Orbigny). Hofker's summary of the main morphological features of *G. cretacea* did not include the presence of widely spaced, twin keels. Hofker did not attempt to produce a full synonymy and gave only important references to the species. This summary indicated that the range of the species, as quoted by the various authors, was totally indecisive.

Hagn (1953: 92; pl. 8, fig. 5) recorded *G. cretacea* from the lower Upper Campanian and indicated that it was found also in the Albian and Cenomanian where it was best referred to *G. infracretacea* Glaessner. Hofker (1961) summarized the development of *G. cretacea* from Glaessner's species as follows:

Aptian – Albian	<i>Praeglobotruncana infracretacea</i> (Glaessner) form
Albian – Cenomanian	<i>Praeglobotruncana</i> sp., cf. <i>P. gautierensis</i> (Brönnimann) form
Cenomanian – Turonian	<i>Praeglobotruncana crassa</i> Bolli form
Turonian – Upper Campanian	<i>Globigerina cretacea</i> d'Orbigny form, with weak ornament
Lower – Upper Maastrichtian	<i>Globigerina cretacea</i> d'Orbigny form, with strong ornament
Upper Maastrichtian	<i>Rugoglobigerina rugosa</i> (Plummer) form – culminating in aberrant forms.

Bandy (1967), without referring to Hofker, and using very different generic determinations, produced a basically similar scheme. However, on the basis of the thinner wall structure, rugose surface, character of the umbilical plate, slope of the chambers and the geological range, he favoured an affinity with the genus *Rugoglobigerina* Bronnimann rather than *Globotruncana* Cushman. Bandy rejects an origin for *G. cretacea* from the *Rugoglobigerina* stock, the *Globotruncana linneiana bulloides* Vogler lineage or the *Praeglobotruncana delrioensis* (Plummer) lineage. He considers it derived from *Hedbergella trochoidea* (Gandolfi), which, at higher levels, does show a tendency to expand its porticus, a process which, if continued, could lead to the formation of a tegilla. Bandy also interpreted the development of faint keels as parallel evolution with *Globotruncana*. Bandy's views differ from those of Hofker only in including the twin keels in the final determination of the species. Both workers consider *R. rugosa* (Plummer) an end member of the lineage.

Pessagno (1967) erected the new genus *Archaeoglobigerina* Pessagno, and a new species (*A. blowi* Pessagno 1967) for specimens immediately ancestral to *A. cretacea* (d'Orbigny). Pessagno records the presence of transitional forms between these two species and an '*A. blowi* stage' in the early whorls of some specimens of '*A. cretacea*'. *A. blowi* is recorded from the Coniacian and Santonian while *A. cretacea* is restricted to the Santonian and Lower Maastrichtian interval. Pessagno was dissatisfied with Banner & Blow's selection of a lectotype, on the grounds that d'Orbigny appeared to indicate a specimen with a more lobulate periphery and a more rapid increase in chamber size in the last whorl. Douglas (1969), however, places *A. cretacea* within the genus *Globotruncana*.

Work on the Albian–Lower Turonian interval shows that the *G. cretacea* lineage originated from *Hedbergella*. Many individuals have been found in the Upper Cenomanian which possess a faint trace of twin keels on some of the chambers of the final whorl. These, but for these faint keels, would be referred to *H. delrioensis* (Carsey), and it is suggested that this species is the initial source of the *G. cretacea* group. In the Albian–Cenomanian interval there is, as already noted, a plexus including *H. infracretacea* (Glaessner), *H. delrioensis* (Carsey) and *H. brittonensis* Loeblisch & Tappan. This evolutionary lineage is included in Fig. 7.

Although the generic determination in the upper levels of the Cretaceous is still in dispute the forms from the Cenomanian, in all but one character, belong in the genus *Hedbergella*. In the Cenomanian apertural modifications are not apparent. The apertural characteristics place these individuals within *Hedbergella*. The 'keels' are not typical of those seen in the *Globotruncana* group, but are produced by an alignment of the surface ornament. This is all these structures

ever become, even in the Maastrichtian, although some of Pessagno's figures indicate structures more prominent than those normally encountered. As these keels are not of the same structure as the normal globotruncanid keel it is thought best to retain the Cenomanian individuals within the genus *Hedbergella*.

RANGE. Rarely seen in the Upper Cenomanian Zone 13, more abundant in the Lower Turonian.

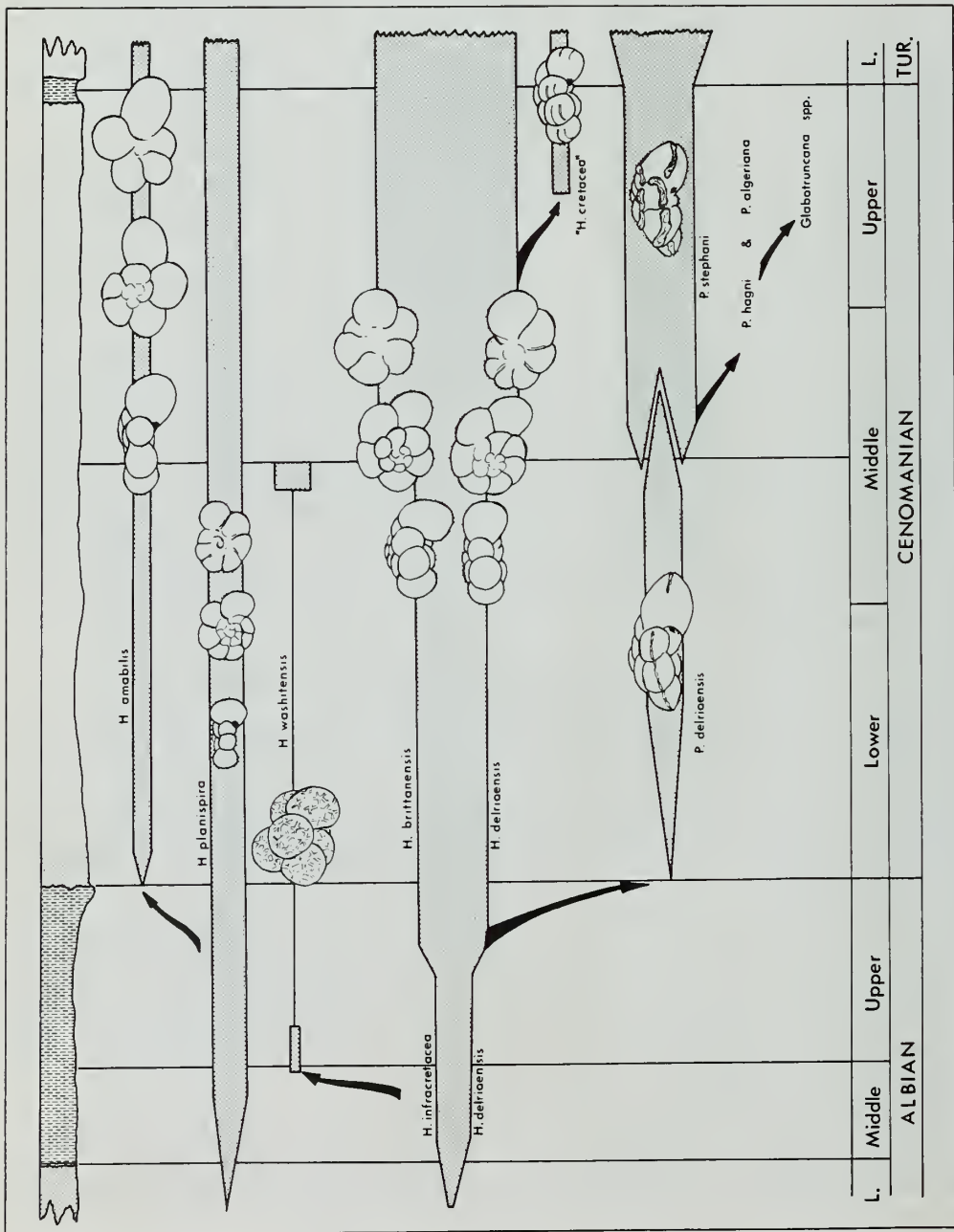


Fig. 7 Evolution of the *Hedbergella* and *Praeglobotruncana* groups.

Hedbergella delrioensis (Carsey 1926)

(Plate 4, figs 1–3)

- 1926 *Globigerina cretacea* d'Orbigny var. *delrioensis* Carsey: 43.
? 1940 *Globigerina cretacea* d'Orbigny; Tappan: 121–122; pl. 19, fig. 11.
? 1943 *Globigerina cretacea* d'Orbigny; Tappan: 512; pl. 82, figs 16–17.
1952 *Globigerina gautierensis* Bronnimann: 11; pl. 1, figs 1–3; text-fig. 2a–c.
1954 *Globigerina delrioensis* Carsey; Frizzell: 127; pl. 20, fig. 1.
1959 *Praeglobotruncana gautierensis* (Brönnimann) Bolli: 265; pl. 21, figs 3–6.
1959 *Praeglobotruncana* (*Hedbergella*) *delrioensis* (Carsey) Banner & Blow: 8.
1960 *Praeglobotruncana gautierensis* (Brönnimann); Jones: 102; pl. 15, figs 1a–c, 2a–c, ? 3, ? 4, 5, ? 6, 7a–c, 8, 9a–c; text-fig. 1.
1962 *Praeglobotruncana gautierensis* (Brönnimann); Pessagno: 358; pl. 6, fig. 4.
1962 *Hedbergella delrioensis* (Carsey) Takayanagi & Iwamoto: 190; pl. 28, figs 10–12.
1963 *Hedbergella delrioensis* (Carsey); Renz, Luterbacher & Schneider: 1083; pl. 9, fig. 5a–c.
1964 *Hedbergella delrioensis* (Carsey); Todd & Low: 402; pl. 1, fig. 2a–c.
1966 *Hedbergella delrioensis* (Carsey); Salaj & Samuel: 167; pl. 8, fig. 5a–c.
1966 *Hedbergella delrioensis* (Carsey); Butt: 173–174; pl. 2, figs 1–8.
1966 *Hedbergella delrioensis* (Carsey); Eicher: 27; pl. 5, fig. 12.
1967 *Hedbergella delrioensis* (Carsey); Pessagno: 282–283; pl. 48, figs 1, 2, 3–5.
1967 *Hedbergella delrioensis* (Carsey); Eicher: 186; pl. 19, fig. 6.
1969b *Hedbergella delrioensis* (Carsey); Eicher: 168, fig. 3.
1970 *Hedbergella delrioensis* (Carsey); Eicher & Worstell: 302; pl. 9, figs 10, 11a–b.

REMARKS. The authors follow the majority of previous workers in their determinations and include within this species all those individuals occurring in the Albian to Turonian interval which possess a moderate to low spire. There is a complete range within *Hedbergella* from forms with an almost flat (*H. planispira* (Tappan)) to a very high spire (*H. brittonensis* Loeblich & Tappan). Many authors have proposed separate specific names for extreme forms and many of the intermediates in the series. However, the authors believe that the variation is continuous and not naturally subdivisible. In the present work, for convenience, the end members of the plexus have been retained as separate species.

The most abundant planktonic species found in the Neocomian to Aptian interval is *Globigerina kugleri* Bolli. This is thought to have evolved into *H. delrioensis* by the development of an extraumbilical aperture and the addition of another chamber in the final whorl. Bandy (1967) considered *H. delrioensis* as the basic stock from which evolved *Globigerinelloides* Cushman & ten Dam, *Hedbergella* Bronnimann & Brown, *Praeglobotruncana* Bermudez, *Schackoina* Thalmann, *Clavihedbergella* Banner & Blow, *Ticinella* Reichel, *Rotalipora* Brotzen and *Globotruncana* Cushman. Bandy's hypothesis is supported by the present research.

RANGE. Recorded from the Middle Albian Zone 4 to the Lower Turonian – although Takayanagi (1965) gives the complete range as Neocomian–Santonian.

Hedbergella infracretacea (Glaessner 1937)

(Plate 3, figs 18–20)

- 1890 *Globigerina cretacea* d'Orbigny; Burrows, Sherborn & Bailey: 561; pl. 11, fig. 18.
1892 *Globigerina cretacea* d'Orbigny; Chapman: 517; pl. 15, fig. 13.
1896 *Globigerina bulloides* d'Orbigny; Chapman: 587; pl. 13, fig. 4a–b.
1896 *Globigerina cretacea* d'Orbigny; Chapman: 588; pl. 13, figs 5–6.
1935a *Globigerina cretacea* d'Orbigny; Eichenberg: 30–31; pl. 6, fig. 4.
1935b *Globigerina cretacea* d'Orbigny; Eichenberg: 395; pl. 5, figs 53–54.
1937 *Globigerina infracretacea* Glaessner: 28; text-fig. 1.
? 1940 *Globigerina cretacea* d'Orbigny; Tappan: 121–122; pl. 19, fig. 11a–c.
? 1943 *Globigerina cretacea* d'Orbigny; Tappan: 512; pl. 82, figs 16–17.
1947 *Globigerina infracretacea* Glaessner; ten Dam: 27–28.
1948a *Globigerina infracretacea* Glaessner; ten Dam: 188–189.
1950 *Globigerina infracretacea* Glaessner; ten Dam: 54.
1951 *Globigerina infracretacea* Glaessner; Noth: 73; pl. 7, fig. 51.
1953 *Globigerina infracretacea* Glaessner; Subbotina: 51; pl. 1, figs 5–10.

- 1954 *Globigerina infracretacea* Glaessner; Bartenstein: 49.
 1957 *Globigerina infracretacea* Glaessner; Said & Bakarat: 45; pl. 1, fig. 27a-c.
 1959 *Praeglobotruncana infracretacea* (Glaessner) Bolli: 266; pl. 21, figs 9, 10; not pl. 22, fig. 1.
 1960 *Globigerina infracretacea* Glaessner; Tollmann: 191; pl. 20, figs 4-5.
 1960a *Globigerina infracretacea* Glaessner; Moullade: 136; pl. 2, figs 18-20.
 1961 *Praeglobotruncana infracretacea* (Glaessner); Hofker: 96.
 1961b *Globigerina infracretacea* Glaessner; Loeblich & Tappan: 276.
 1963 *Hedbergella delrioensis* (Carsey); Maslakova: 114 (part).
 1963 *Hedbergella infracretacea* (Glaessner) Renz, Luterbacher & Schneider: 1083.
 1965 *Globigerina infracretacea* Glaessner; Neagu: 36; pl. 10, figs 10-12.
 1966 *Hedbergella infracretacea* (Glaessner); Salaj & Samuel: 169; pl. 8, fig. 8a-c.
 1966 *Hedbergella infracretacea* (Glaessner); Glaessner (emend.): 179-183; pl. 1, figs 1-3.
 1967 *Hedbergella infracretacea* (Glaessner); Fuchs: 331; pl. 17, fig. 13a-c.
 1967 *Hedbergella infracretacea* (Glaessner); Uguzzoni & Radrizzani: 1226; pl. 92, figs 7a-c, 8a-b.
 1972 *Hedbergella infracretacea* (Glaessner); Gawor-Biedowa: 69-70; pl. 6, fig. 8a-c.

REMARKS. This species has been emended by Glaessner, who noted the great variation both in elevation of the spire and position of the aperture. In 1961 Loeblich & Tappan regarded *H. infracretacea* as similar to, and possibly synonymous with, *H. delrioensis*, differing only in being half the size. Glaessner, after studying the type specimens, concluded that *H. infracretacea* could be differentiated by its higher spire and relatively smaller size. *H. infracretacea* is now regarded as a morphologically primitive member of the genus *Hedbergella*.

RANGE. Middle and Upper Albian Zones 4-6.

Hedbergella planispira (Tappan 1940)
 (Plate 4, figs 4-6)

- 1940 *Globigerina planispira* Tappan: 12; pl. 19, fig. 12.
 1943 *Globigerina planispira* Tappan; Tappan: 513; pl. 83, fig. 3.
 1948 *Globigerina almadenensis* Cushman & Todd: 95; pl. 16, figs 18, 19.
 1949 *Globigerina globigerinelloides* Subbotina: 32; pl. 2, figs 11-16.
 1953 *Globigerina globigerinelloides* Subbotina; Subbotina: pl. 1, figs 11, 12.
 1954 *Globorotalia ? youngi* Fox: 119; pl. 26, figs 15-18.
 1956 *Hedbergina seminolensis* (Harlton); Brönnimann & Brown: 529; pl. 20, figs 4-6.
 1957a *Praeglobotruncana planispira* (Tappan) Bolli, Loeblich & Tappan: 40; pl. 9, fig. 3.
 1959 *Praeglobotruncana modesta* Bolli: 267; pl. 22, fig. 2.
 1959 *Praeglobotruncana planispira* (Tappan); Bolli: 267; pl. 22, figs 3-4.
 1961b *Hedbergella planispira* (Tappan) Loeblich & Tappan: 276-277; pl. 5, figs 4-11.
 1964 *Hedbergella planispira* (Tappan); Olsson: 161-162; pl. 1, figs 4, 5.
 1964 *Hedbergella planispira* (Tappan); Todd & Low: 402.
 1965 *Hedbergella planispira* (Tappan); Takayanagi: 205; pl. 21, figs 6a-7c.
 1965 *Hedbergella planispira* (Tappan); Eicher: 905; pl. 106, fig. 1.
 1967 *Hedbergella planispira* (Tappan); Pessagno: 283-284; pl. 51, fig. 1; pl. 53, figs 1-4.
 1967 *Hedbergella planispira* (Tappan); Eicher: 186; pl. 19, fig. 3.
 1969b *Hedbergella planispira* (Tappan); Eicher: 168, text-fig. 3.
 1969b *Hedbergella planispira* (Tappan); Douglas: 168; pl. 5, fig. 1.
 1970 *Hedbergella planispira* (Tappan); Eicher & Worstell: 302, 304; pl. 9, figs 12, 13a-c.
 1972 *Hedbergella planispira* (Tappan); Gawor-Biedowa: 70-71; pl. 5, fig. 8a-c.

REMARKS. This small, distinctive species is found throughout the greater part of the Albian and Cenomanian in England. Although the majority of the specimens are characteristic of the species as generally understood, occasionally larger, more robust specimens are encountered. These may belong to *H. trochoidea* (Gandolfi).

The dimensions of *H. planispira* and *H. trochoidea* given by Loeblich & Tappan (1961b) are as follows.

- H. planispira* – holotype diameter 0.24 mm; thickness 0.11 mm
 range of diameter 0.11-0.26 mm
H. trochoidea – holotype diameter 0.39 mm; thickness 0.18 mm
 range of diameter 0.26-0.39 mm

Loeblich & Tappan suggested that *H. trochoidea* differs from *H. planispira* in being three times as large, displaying greater increase in chamber size and a more rugose surface, but the figures quoted above show that there is no firm dividing line between the two species. In many of the species of *Hedbergella* larger chambers usually display a coarser rugosity and neither chamber size nor rugosity can be relied on for specific differentiation. In England forms very similar to *H. trochoidea* occur at certain levels and there is a possibility that these are ecophenotypic variants of *H. planispira*. This relationship would explain the difficulty many workers have found in differentiating these species. Other specimens could equally well be placed in *H. delrioensis*, and many workers prefer to regard this as a synonym. In the present work no specimens have been found that can be certainly referred to *H. trochoidea*.

RANGE. Middle Albian Zone 4 to Upper Cenomanian Zone 14; occurs in reduced numbers in the Lower Turonian.

Hedbergella washitensis (Carsey 1926)

(Plate 2, fig. 16)

- 1926 *Globigerina washitensis* Carsey: 44; pl. 7, fig. 10; pl. 8, fig. 2.
- 1931 *Globigerina washitensis* Carsey; Plummer: 193; pl. 13, fig. 12.
- 1940 *Globigerina washitensis* Carsey; Tappan: 122; pl. 19, fig. 13.
- 1943 *Globigerina washitensis* Carsey; Tappan: 513; pl. 83, figs 1-2.
- 1944 *Globigerina washitensis* Carsey; Lozo: 563; pl. 3, fig. 4.
- 1949 *Globigerina washitensis* Carsey; Loeblich & Tappan: 265; pl. 51, fig. 4.
- 1954 *Globigerina washitensis* Carsey; Frizzell: 127; pl. 20, fig. 9.
- 1956 *Globigerina washitensis* Carsey; Bolin: 293; pl. 39, figs 2-3; text-fig. 5 (11a-b).
- 1959 *Globigerina washitensis* Carsey; Bolli: 271; pl. 23, figs 6-7.
- 1961b *Hedbergella washitensis* (Carsey) Loeblich & Tappan: 278; pl. 4, figs 9-11.
- 1962 *Hedbergella washitensis* (Carsey); Ayala-Castanares: 22; pl. 2, fig 1a-c.
- 1967 *Hedbergella washitensis* (Carsey); Pessagno: 284-285; pl. 49, fig. 1.
- 1967 *Globigerina washitensis* Carsey; Bandy: 8; text-fig. 3.

REMARKS. The very characteristic appearance of this species is reflected in the unanimity of the synonymy. The only apparent dissension is that of Bandy (1967), who returns this species to the genus *Globigerina*. We feel that this is not justified, as the development of the species from the *H. infracretacea* (Glaessner) stock is probable. The latter often shows the final chamber overhanging the umbilicus, and little modification would be required to produce the highly enrolled *H. washitensis*.

The distribution of this species in England is interesting and requires discussion. Although rare specimens have been found in the upper part of the Gault Clay (Upper Albian) and in the lowermost Lower Chalk (Lower Cenomanian) there are only two levels where specimens can be regularly found. The first is at the non-sequence at the base of the Upper Gault Clay (*cristatum* Subzone). The forms seen at this level approach *H. hiltermanni* Loeblich & Tappan, possess a coarser ornament and are generally flatter-spined than those found at the other level of abundance, which occurs immediately prior to the major non-sequence in the mid-Cenomanian (Carter & Hart in the discussion of Kennedy 1969). In the Chalk *H. washitensis* can be used as an indicator of the latter level throughout the whole of southern England.

The more important occurrences of this species are in close stratigraphic proximity to non-sequences and erosion surfaces, and therefore indicate that this species may only be an ecologically controlled variant of *Hedbergella* produced by the changing environments that preceded such features. A change of environment is suggested by the macrofauna, especially in the mid-Cenomanian, where *H. washitensis* is restricted to a band containing abundant *Orbirhynchia mantelliana* (J. Sowerby). In his account of the Lower Chalk Kennedy (1969) does not give reasons for concentration of brachiopods in this band. The occurrence of *H. washitensis* in the Cenomanian Sands of Devon is significant, as these were deposited in a shallow sea very close to the Cenomanian shoreline. Recent research has produced specimens of *H. delrioensis* from even nearer the shoreline (from the Haldon Hills - see Fig. 1, p. 5). In these marginal areas the surface reticulation

is slightly different from that on specimens from the south-east of England, and this change could be ecologically induced.

RANGE. Appearing at the base of the Upper Albian the species is found up to the *O. mantelliana* Band, immediately preceding the mid-Cenomanian non-sequence.

Genus ***PRAEGLBOTRUNCANA*** Bermudez 1952

TYPE SPECIES. *Globorotalia delrioensis* Plummer 1931.

Praeglobotruncana algeriana Caron 1966
(Plate 3, figs 1–3)

- 1936 *Globotruncana appenninica* – *Globotruncana linnei* Renz: 34; pl. 6, figs 18–20; table 8, fig. 2.
1945 *Globotruncana renzi* Thalmann: 405.
1949 *Globotruncana* (*Globotruncana*) aff. *renzi* Thalmann-Gandolfi; Reichel: 612–613; pl. 16, fig. 8, pl. 17, fig. 8.
1960a *Praeglobotruncana renzi* (Thalmann) Klaus: 795–796; pl. 6, fig. 4a–c.
1961a *Praeglobotruncana renzi* (Thalmann); Malapris & Rat: 90–91; pl. 2, fig. 5a–c; text-fig. 6.
1966 *Praeglobotruncana renzi* (Thalmann); Eicher: 28–29; pl. 6, fig. 9.
1966 *Praeglobotruncana algeriana* Caron: 74–75.
1966 *Praeglobotruncana* cf. *algeriana* Caron; Caron: 75–76; pl. 2, fig. 5a–c.
1969 *Praeglobotruncana algeriana* Caron; Neagu: 142; pl. 17, figs 8–15; pl. 20, figs 4–6; pl. 22, figs 7–8; pl. 23, figs 1–2.

REMARKS. This species is very close to *P. hagni* Scheibnerova, and several specimens from the Plenus Marls appear intermediate between the two forms (see Pl. 3, figs 4–6). Both arise from the *P. delrioensis* (Plummer)/*P. stephani* (Gandolfi) lineage in the Upper Cenomanian, although they only attain their maximum development in the Lower Turonian. The main difference between this species and *P. hagni* is in the more elevated dorsal side and the slightly less convex ventral side. Butt (1966), in his figures of *P. hagni*, included several individuals very similar to *P. algeriana*, and a study of the holotypes may prove the two to be synonymous.

Neagu (1969) recorded this species as the earliest member of the twin-keeled *Praeglobotruncana* group found in the eastern Carpathians, but in Britain *P. hagni* has been recorded at a lower level, although specimens are rare.

RANGE. Upper Cenomanian Zone 13, Plenus Marls Zone 14; continuing into the Lower Turonian in greater numbers.

Praeglobotruncana delrioensis (Plummer 1931)
(Plate 4, figs 22–24)

- 1931 *Globorotalia delrioensis* Plummer: 199; pl. 13, fig. 2a–c.
non 1940 *Globorotalia delrioensis* Plummer; Tappan: 123; pl. 19, fig. 14.
1946 *Globorotalia marginaculeata* Loeblich & Tappan: 257; pl. 37, figs 19–21; text-fig. 4a.
non 1946 *Globorotalia delrioensis* Plummer; Loeblich & Tappan: 257; text-fig. 4b.
1950 *Globotruncana stephani* Gandolfi; Mornod: 587; pl. 15, figs 9a–r, 10, 17; text-fig. 10(1–3).
1952 *Praeglobotruncana delrioensis* (Plummer) Bermudez: 52; pl. 7, fig. 1.
1954 *Globorotalia delrioensis* Plummer; Frizzell: 129; pl. 20, fig. 27.
1954 *Globotruncana stephani* Gandolfi; Hagn & Zeil: 33; pl. 2, fig. 7; pl. 5, figs 7–8.
1956 *Praeglobotruncana delrioensis* (Plummer); Brönnimann & Brown: 53; pl. 21, figs 8–10; pl. 24, figs ? 16, 17, text-figs 9, 13a, b, d, ? 15c–f; not text-figs 16c, d, e.
1957 *Praeglobotruncana delrioensis* (Plummer); Bolli, Loeblich & Tappan: 39; pl. 9, fig. 1.
1957 *Praeglobotruncana* cf. *delrioensis* (Plummer); Bolli, Loeblich & Tappan: 55; pl. 12, fig. 4.
non 1957 *Praeglobotruncana delrioensis* (Plummer); Zeigler: 199.
1959 *Praeglobotruncana* (*Praeglobotruncana*) sp. cf. *stephani* (Gandolfi); Banner & Blow: pl. 3, fig. 4.
1960a *Praeglobotruncana delrioensis* (Plummer); Klaus: 793–794; pl. 6, fig. 1a–c.
1960b *Praeglobotruncana delrioensis* (Plummer); Klaus: 300–301, text-fig. 1a.
1961b *Praeglobotruncana delrioensis* (Plummer); Loeblich & Tappan: 280–284; pl. 6, figs 9–12.
1963 *Praeglobotruncana delrioensis* (Plummer); Salaj & Samuel: 104–105; tab. 6, fig. 4a–c.

- non 1964 *Praeglobotruncana delrioensis* (Plummer); Todd & Low: 404; pl. 2, fig. 4.
 1966 *Praeglobotruncana delrioensis* (Plummer); Salaj & Samuel: 188; pl. 15, fig. 3a–c.
 1967 *Praeglobotruncana delrioensis* (Plummer); Pessagno: 286–287; pl. 52, figs 3–5; pl. 100, fig. 7.

REMARKS. This species has been confused in the literature with *P. stephani* (Gandolfi) and was regarded as synonymous with it by Bronnimann & Brown (1956: 531), Zeigler (1957: 199) and Banner & Blow (1959: 8).

Loeblich & Tappan (1961b) claim that the two species are quite distinct. They also claim that there is great variation within *P. delrioensis* and include *P. marginaculeata* (Loeblich & Tappan) within its synonymy. However, when studying complete sequences of strata sampled at close, regular intervals, none of these species can be separated. It is true that the type specimens are distinct – hence the retention of the specific names – but it is also clear that they belong in a single evolutionary plexus beginning with *P. delrioensis*. This has already been recognized by Klaus (1960b: 285–308), who showed, using statistical methods, that all three species belong to the one lineage. The overlap of characters makes accurate differentiation impossible, and *P. delrioensis* is seen to evolve imperceptibly into *P. stephani* during the mid-Cenomanian.

P. delrioensis probably evolved from *Hedbergella delrioensis* in the lowermost Cenomanian, and the first transitional forms appear at the Albian/Cenomanian boundary irrespective of the facies involved.

RANGE. Lower Cenomanian Zones 7–11(i).

***Praeglobotruncana hagni* Scheibnerova 1962**
 (Plate 3, figs 10–12)

- 1962 *Praeglobotruncana hagni* Scheibnerova: 219, 225–226; text-fig. 6a–c.
 1966 *Praeglobotruncana hagni* Scheibnerova; Caron: 76; pl. 2, fig. 6a–c.
 1966 *Praeglobotruncana* sp. cf. *P. hagni* Scheibnerova; Butt: 174; pl. 3, figs 1, ? 2, ? 3, ? 4.

REMARKS. *P. hagni* is normally characterized by an almost flat dorsal surface, although some specimens with a convex dorsal surface have been found. All specimens have a more or less developed double keel. The aperture is largely extraumbilical and this places the species within the definition of *Praeglobotruncana*.

The species is probably synonymous with *Globotruncana roddai* (Marianos & Zingula 1966: 340; pl. 39, fig. 6a–c). Douglas (1969a, b) also described this species from the Turonian of California, including it in *Praeglobotruncana*. His illustrations of *P. roddai*, as well as its recorded position in the California succession, shows it to be a junior synonym of *P. hagni*.

P. hagni, while appearing in the Upper Cenomanian, is more frequently found in the Lower Turonian, especially in the lower levels of the Frétevou Chalk (Butt 1966). Similar numbers are found only in the upper beds of the Plenus Marls, and the lower levels of the Middle Chalk. The relationship of the British and French populations will be discussed in the following stratigraphic account.

RANGE. Upper Cenomanian Zones 13–14; Lower Turonian, with levels of greater abundance in Zone 14(iib) (Plenus Marls Beds 4–8).

***Praeglobotruncana* cf. *helvetica* (Bolli 1945)**
 (Plate 3, figs 16–17)

- cf. 1945 *Globotruncana helvetica* Bolli: 226; pl. 9, figs 6–8; text-fig. 1 (9–12).

REMARKS. This typically Turonian species has not been studied in detail as few specimens have been found. In the upper levels of the Plenus Marls (Beds 4–8) atypical forms have been found – adding weight to the placing of the Cenomanian/Turonian boundary at a level within the marl unit.

The main feature of interest are the rare finds of specimens of a ‘*helvetica*’ type in Zone 13 of the Upper Cenomanian. Some of the specimens are very close to *P. helvetica*, while others appear to be closely similar to *Hedbergella delrioensis*, having developed a very flat spire and the faint trace of the characteristic *Praeglobotruncana* keel. This indicates that *P. helvetica* may have

developed from the *H. delrioensis* lineage instead of from the *P. delrioensis* lineage as was suggested by Bandy (1967). He postulated that by development of a flat dorsal surface and inflation of the chambers ventrally *P. helvetica* could have been produced from *P. delrioensis*. However, the *Praeglobotruncana* lineage does not show this transition to a lower spire. The main trend through *P. stephani* to forms described as *P. stephani* var. *turbinata* Reichel indicates a progressive increase in spire height. The only reduction of this feature is seen in the transitional sequence through *P. hagni* to *Globotruncana* cf. *indica* Jacob & Sastri of Pessagno, which is accompanied by the development of the second keel, there being no indication of any trend towards a form that could be related to *P. helvetica*.

RANGE. Very primitive forms have been found in the Upper Cenomanian, although typical specimens are only encountered in the overlying Turonian.

Praeglobotruncana stephani (Gandolfi 1942)

(Plate 4, figs 16–21)

- 1942 *Globotruncana stephani* Gandolfi: 130; pl. 3, figs 4, 5; pl. 4, figs 36, 37, 41–45; pl. 6, figs 4, 6; pl. 9, figs 5, 8; pl. 13, fig. 5; pl. 14, fig. 2.
- 1942 *Globotruncana appenninica* var. *beta* Gandolfi: 119, text-fig. 41 (2a–b).
- 1945 *Globotruncana stephani* Gandolfi; Bolli: 224 (part); text-fig. 1 (3, 4); pl. 9, fig. 2.
- 1948 *Globorotalia californica* Cushman & Todd: 96; pl. 16, figs 22, 23.
- 1950 *Globotruncana (Globotruncana) stephani* Gandolfi; Reichel: 609; pl. 16, fig. 6; pl. 17, fig. 6.
- 1953 *Rotundina stephani* (Gandolfi) Subbotina: 165; pl. 2, figs 5–7; pl. 3, figs 1–3.
- 1954 *Globotruncana stephani* Gandolfi; Ayala-Castanares: 412; pl. 11, fig. 2.
- 1955 *Globotruncana (Rotundina) aumalensis* (Sigal); Küpper: 116; pl. 18, fig. 5.
- 1955 *Globotruncana (Rotundina) stephani* Gandolfi; Küpper: 116; pl. 18, fig. 6.
- 1956 *Globotruncana (Praeglobotruncana) renzi* (Thalmann & Gandolfi) subsp. *primitiva* Küpper: 43; pl. 8, fig. 2a–c.
- 1957a *Praeglobotruncana stephani* (Gandolfi) Bolli, Loeblich & Tappan: 39; pl. 9, fig. 2.
- 1959 *Globotruncana kupperi* Thalmann: 130.
- 1959 *Praeglobotruncana stephani* (Gandolfi); Orlov: text-fig. 687a–c.
- 1959 *Praeglobotruncana (Praeglobotruncana) stephani* (Gandolfi); Banner & Blow: 3, text-fig. 1a.
- 1960a *Praeglobotruncana stephani* (Gandolfi); Klaus: 794; pl. 6, fig. 2a–c.
- 1961b *Praeglobotruncana stephani* (Gandolfi); Loeblich & Tappan: 284–290; pl. 6, figs 1–8.
- 1963 *Rotundina stephani* (Gandolfi); Salaj & Samuel: 103–104; pl. 6, figs 2a–c, 3a–c.
- 1964 *Praeglobotruncana stephani* (Gandolfi); Loeblich & Tappan: C659, fig. 527, 3a–c.
- 1966 *Praeglobotruncana stephani* (Gandolfi); Eicher: 28; pl. 6, fig. 4.
- 1966 *Praeglobotruncana stephani* (Gandolfi); Douglas & Slitter: 107; pl. 5, fig. 1a–c; not pl. 4, fig. 1a–c.
- 1966 *Rotundina stephani* (Gandolfi); Salaj & Samuel: 195; pl. 33, fig. 8.
- 1967 *Praeglobotruncana stephani* (Gandolfi); Pessagno: 287; pl. 50, figs 9–11.
- 1969b *Praeglobotruncana stephani* (Gandolfi); Douglas: 173; pl. 2, fig. 1.
- 1969b *Praeglobotruncana delrioensis* (Plummer); Eicher: 169.
- 1970 *Praeglobotruncana stephani* (Gandolfi); Eicher & Worstell: 308; pl. 10, fig. 9; pl. 11, figs 2a–c, 3.
- 1972 *Praeglobotruncana stephani* (Gandolfi); Gawor-Biedowa: 76–78; pl. 8, fig. 1a–c.

REMARKS. This species occurs in the Upper Cenomanian (Zones 11(ii) to 13), and at these levels is often present in substantial numbers. Above the Plenus Marls, in the Lower Turonian, it becomes one of the dominant planktonic species.

In Zone 13 of the Upper Cenomanian the general trend towards increasing ornamentation accelerates and is associated with an increase in height of the spire. Extreme variants are referable to Reichel's (1950) var. *turbinata*, which we include within the synonymy of *P. stephani*. The most important references to *P. stephani* var. *turbinata* are as follows.

- 1950 *Globotruncana stephani* Gandolfi var. *turbinata* Reichel: 609.
- 1950 *Globotruncana stephani* Gandolfi var. *turbinata* Reichel; Mornod: 589, text-fig. 17 (1–3); pl. 15, figs 9a–r, 18–20, not 10–17.
- 1954 *Globotruncana stephani* Gandolfi var. *turbinata* Reichel; Hagn & Zeil: 34; pl. 2, fig. 2; pl. 5, figs 3–4.
- 1954 *Globotruncana stephani* Gandolfi var. *turbinata* Reichel; Ayala-Castanares: 412; pl. 11, fig. 3.
- 1956 *Globotruncana (Praeglobotruncana) stephani* Gandolfi *turbinata* Reichel; Küpper: 43; pl. 8, fig. 1a–c.

- 1956 *Praeglobotruncana delrioensis* var. *turbinata* (Reichel) Bronnimann & Brown: 532; text-fig. 16c-e.
 1957 *Globotruncana* (*Globotruncana* ?) *stephani turbinata* Reichel; Gandolfi: 62; pl. 9, fig. 4.
 1960a *Praeglobotruncana stephani* var. *turbinata* (Reichel) Klaus: 795; pl. 6, fig. 3a-c.

Other variants lead to forms related to *P. hagni* and *P. algeriana*. In the upper levels of the Cenomanian all the variants of the *Praeglobotruncana* plexus occur, and the relationships of these species are shown in Fig. 7 (p. 34).

RANGE. Cenomanian Zone 11(ii) to Lower Turonian.

Subfamily ROTALIPORINAE Sigal 1958

Genus *ROTALIPORA* Brotzen 1942

TYPE SPECIES. *Rotalipora turonica* Brotzen 1942, = *Globorotalia cushmani* Morrow 1934.

Rotalipora cushmani (Morrow 1934)

(Plate 2, fig. 18; Plate 4, figs 7-9)

- 1934 *Globorotalia cushmani* Morrow: 199; pl. 31, figs 2, 4.
 1942 *Rotalipora turonica* Brotzen: 32, text-figs 10, 11 (4).
 1945 *Globotruncana alpina* Bolli: 224-225; pl. 9, figs 3, 4.
 1946 *Globorotalia cushmani* Morrow; Cushman: 152; pl. 62, fig. 9a-c.
 1948 *Globotruncana benacensis* Cita: 147-148; pl. 3, fig. 3a-c.
 1948 *Rotalipora cushmani* (Morrow) Sigal: 96; pl. 1, fig. 2; pl. 2, fig. 1.
 1950 *Globotruncana* (*Rotalipora*) *montsalvensis* Mornod: 584, text-figs 4 (1), 7 (1, 2).
 1950 *Globotruncana* (*Rotalipora*) *montsalvensis* var. *minor* Mornod: 586, text-fig. 8 (1a-c, 2, 4).
 1950 *Globotruncana* (*Rotalipora*) *turonica* (Brotzen); Reichel: 607; pl. 16, fig. 5; pl. 17, fig. 5.
 1952 *Globotruncana* (*Rotalipora*) *turonica* (Brotzen) var. *expansa* Carbonnier: 118; pl. 6, fig. 4.
 1954 *Rotalipora cushmani* (Morrow); Ayala-Castanares: 418; pl. 16, fig. 2.
 1954 *Rotalipora turonica* Brotzen; Ayala-Castanares: 422; pl. 14, fig. 2.
 1954 *Globorotalia cushmani* Morrow; Frizzell: 129; pl. 20, fig. 28.
 1954 *Rotalipora turonica* Brotzen; Hagn & Zeil: 27-28; pl. 1, fig. 5; pl. 4, fig. 4, not fig. 3.
 1954 *Rotalipora cushmani* (Morrow); Hagn & Zeil: 29; pl. 1, fig. 3; pl. 4, figs 8-10.
 1954 *Rotalipora montsalvensis* Mornod; Hagn & Zeil: 29; pl. 1, fig. 4; pl. 5, fig. 2.
 1954 *Rotalipora turonica* subsp. *thomei* Hagn & Zeil: 28; pl. 1, fig. 6; pl. 4, figs 5-6.
 1956 *Rotalipora cushmani* (Morrow); Brönnimann & Brown: 537; pl. 20, figs 10-12.
 1957 *Rotalipora cushmani* (Morrow); Sacal & Debourle: 58; pl. 25, figs 6-8, 13, 16, 17.
 1957a *Rotalipora turonica* Brotzen; Bolli, Loeblich & Tappan: 41; pl. 9, fig. 6a-c.
 1957 *Globotruncana* (*Rotalipora*) sp. cf. *G. (R.) turonica* Brotzen; Edgell: 109; pl. 1, figs 16, 18.
 1960a *Rotalipora* (*Rotalipora*) cf. *montsalvensis* var. *minor* Mornod; Klaus: 813-814; pl. 5, fig. 1a-c.
 1960a *Rotalipora* (*Rotalipora*) *cushmani* (Morrow); Klaus: 814-815; pl. 5, fig. 2a-c.
 1960a *Rotalipora* (*Rotalipora*) *turonica* Brotzen var. *expansa* Carbonnier; Klaus: 815-816; pl. 5, fig. 4a-c.
 1961b *Rotalipora cushmani* (Morrow); Loeblich & Tappan: 297-298; pl. 8, figs 1-10.
 1964 *Rotalipora montsalvensis* Mornod; Renz, Luterbacher & Schneider: 1089; pl. 7, fig. 1a-c.
 1964 *Rotalipora montsalvensis minor* Mornod; Renz, Luterbacher & Schneider: 1089; pl. 7, fig. 2a-c.
 1964 *Rotalipora cushmani* (Morrow); Loeblich & Tappan: C659-C661; fig. 528, 1a-c, 2a-c.
 1966 *Rotalipora cushmani expansa* (Carbonnier); Salaj & Samuel: 183-184; pl. 12, fig. 7a-c.
 1966 *Rotalipora cushmani montsalvensis* (Mornod); Salaj & Samuel: 184; pl. 13, fig. 5a-c.
 1966 *Rotalipora cushmani cushmani* (Morrow); Salaj & Samuel: 184-185; pl. 13, figs 2a-c, 4a-c.
 1966 *Rotalipora cushmani minor* (Mornod); Salaj & Samuel: 185; pl. 13, fig. 6a-c.
 1966 *Rotalipora cushmani thomei* Hagn & Zeil; Salaj & Samuel: 185; pl. 12, fig. 6a-c.
 1966 *Rotalipora cushmani turonica* Brotzen; Salaj & Samuel: 185-186; pl. 13, fig. 1a-c; pl. 14, fig. 1a-c.
 1967 *Rotalipora cushmani* (Morrow); Pessagno: 292-293; pl. 51, figs 6-9; pl. 101; figs 5-7.
 1967 *Rotalipora cushmani* (Morrow); Marks: 272-273; pl. 1, figs 1-12; pl. 2, figs 1-3.
 1969b *Rotalipora cushmani* (Morrow); Douglas: 173-174; pl. 1, figs 1-2.
 1969 *Rotalipora cushmani* (Morrow); Scheibnerova: 66; pl. 11, figs 2a-c, 5a-c.
 1970 *Rotalipora cushmani* (Morrow); Eicher & Worstell: 310, 312; pl. 12, figs 3a-c, 4a-c; pl. 13, fig. 1a-b.
 1972 *Rotalipora cushmani cushmani* (Morrow); Gawor-Biedowa: 79-81; pl. 10, figs 1a-c, 2a-c.

REMARKS. This is one of the most conspicuous species of foraminifera in the British Upper Cenomanian. It appears in large numbers in the mid-Cenomanian, while below that level small

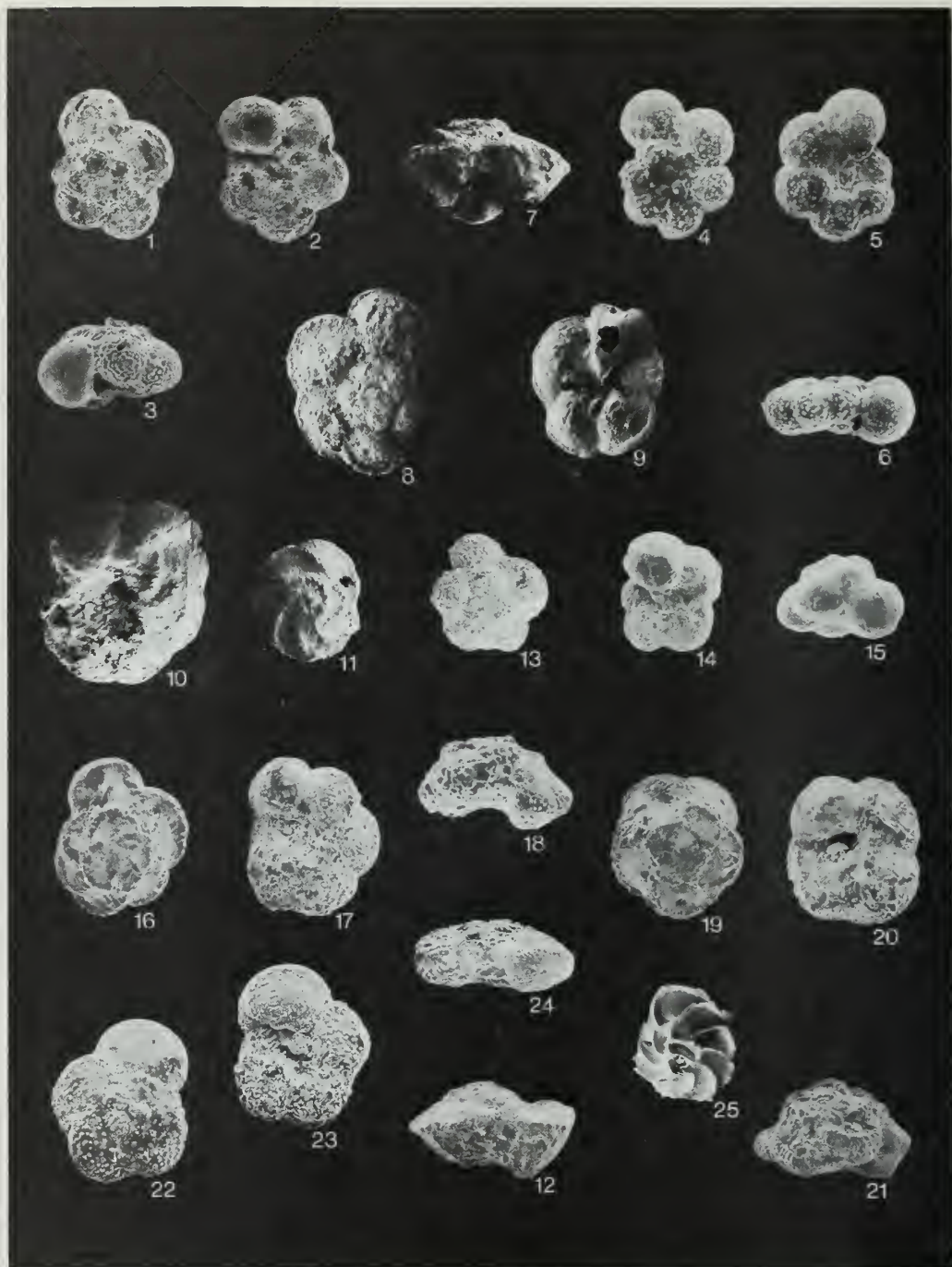


Plate 4

Figs 1-3 *Hedbergella delrioensis* (Carsey). P 50020. Dorsal, ventral and peripheral views. Upper Cenomanian Zone 14(ia), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. $\times 52$.

forms, probably juveniles, occasionally occur. The latter have smooth, inflated chambers, and some individuals show only the slightest trace of a keel. These early representatives are very similar in appearance to *R. evoluta* Sigal and it is possible that this may be the ancestral form of the species. In England the ranges of *R. cushmani* and *R. evoluta* certainly suggest that the former could be derived from the latter. In the Lower Chalk *R. evoluta* is recorded from the lower levels, giving way in the mid-Cenomanian to a population dominated by *R. cushmani*. At no time below this level is *Rotalipora* so dominant an element of the fauna. The overall distribution in the British Isles agrees completely with the scheme of subzones proposed by Pessagno (1967), who divided the Cenomanian into a lower *R. evoluta* Subzone and an upper *R. cushmani*/*R. greenhornensis* (Morrow) Subzone.

An Upper Cenomanian distribution of *R. cushmani* has been recorded by Bandy (1967), Douglas (1969a, b), Eicher (1969b), Eicher & Worstell (1970), Hanzlikova (1961), Klaus (1960a, c), Loeblich & Tappan (1961b), Salaj & Samuel (1963), Scheibnerova (1962) and Zeigler (1957). An account by Marks (1967) showed that *R. cushmani* occurs in some abundance throughout the Craie de Théligny (Sarthe), France. This formation is a lateral equivalent of the upper part of the Grès du Maine (Middle Cenomanian). In the type Cenomanian succession, therefore, *R. cushmani* appears in the upper half of the Middle Cenomanian. Unfortunately the Upper Cenomanian of the type area is composed of the Sables du Perche and the Marnes à Huîtres, and *R. cushmani* has not so far been recorded from these formations, giving no data for the upper limit of the species. Some conclusions can be reached, however, on the basis of the type Turonian succession. This was studied by Butt (1966), and at no level in it has *R. cushmani* been found. In view of this evidence, and the work of one of us (Hart 1975), it must be concluded that *R. cushmani* is restricted to, and characteristic of, the upper half of the Cenomanian. Marks (1967), on the basis of his work on the type Cenomanian, also came to this conclusion, and compared this range with all those previously recorded for the species. The total range of *R. cushmani* has been variously cited within the Middle Cenomanian to Lower Turonian interval, although some authors, e.g. Cushman (1946) and Frizzell (1954), have recorded a range of Lower to Upper Turonian. On the basis of the type Cenomanian succession, as well as the Lower Chalk succession of south-east England, the range is recorded as upper Middle Cenomanian and Upper Cenomanian only.

More recently Salaj & Samuel (1966) have provided data on six subspecies of *R. cushmani*, namely *R. c. cushmani*, *R. c. expansa*, *R. c. thomei*, *R. c. montsalvensis*, *R. c. minor* and *R. c. turonica*. The linear dimensions of all these subspecies, as well as most other characteristics, overlap in range and probably cannot be used for their certain differentiation. Forms like *R. c. minor* have not been encountered by us and the true value of this separation cannot be assessed. Specimens referable to *R. c. thomei* can be found in the Upper Cenomanian of south-east England.

Figs 4–6 *Hedbergella planispira* (Tappan). P 50021. Dorsal, ventral and peripheral views. Upper Albian Zone 6, Bed XIII, Cheriton, Folkestone, Kent. $\times 27$.

Figs 7–9 *Rotalipora cushmani* (Morrow). P 50022–4. Peripheral, dorsal and ventral views. Upper Cenomanian Zone 13, Maiden Newton, Dorset. Fig. 7, $\times 46$; Figs 8, 9, $\times 48$. (See also Pl. 2, fig. 18.)

Figs 10–12 *Rotalipora greenhornensis* (Morrow). Figs 10, 12, P 50026, $\times 42$; Fig. 11, P 50025, $\times 44$. Ventral, dorsal and peripheral views. Upper Cenomanian Zone 13, Maiden Newton, Dorset.

Figs 13–15 *Hedbergella brittonensis* Loeblich & Tappan. P 50027. Dorsal, ventral and peripheral views. Upper Cenomanian Zone 14(ia), Bed C, Cenomanian Limestones, Bovey Lane Sandpit, Beer, near Seaton, Devon. $\times 50$.

Figs 16–21 *Praeglobotruncana stephani* (Gandolfi). Figs 16–18, P 50028–30. Dorsal, ventral and peripheral views. Upper Cenomanian Zone 13, Buckland Newton, Dorset. Figs 19–21, P 50031–3. Specimens referable to the high-spined variant placed by many authors in *P. stephani* var. *turbinata* Reichel. Dorsal, ventral and peripheral views. Upper Cenomanian Zone 13, Beachy Head, near Eastbourne, Sussex. Fig. 16, $\times 45$; Fig. 17, $\times 57$; Fig. 18, $\times 61$; Figs 19, 20, $\times 48$; Fig. 21, $\times 67$.

Figs 22–24 *Praeglobotruncana delrioensis* (Plummer). P 50034. Dorsal, ventral and peripheral views. Middle Cenomanian Zone 10, Beachy Head, near Eastbourne, Sussex. $\times 72$.

Fig. 25 *Epistomina spinulifera* (Reuss). P 50038. Dorsal view. Middle Albian Zone 4, Bed VII, Copt Point, Folkestone, Kent. $\times 19$.

This was initially described by Hagn & Zeil (1954) as a variety of the parent species. In large populations, however, even this form merges with the variations included in the original species.

RANGE. Rare, primitive forms are encountered in the lower part of the Middle Cenomanian, but large numbers of typical individuals appear only above the mid-Cenomanian non-sequence, dominating Zones 11(ii), 12, 13 and 14(i-iii) (Plenus Marls Beds 1-3). The species does not range above the Cenomanian Stage.

Rotalipora evoluta Sigal 1948

(Plate 3, figs 13-15)

- 1940 *Globorotalia delrioensis* Plummer; Tappan: 123; pl. 19, fig. 14.
1946 *Globorotalia delrioensis* Plummer; Loeblich & Tappan: 257, text-fig. 4B.
1948 *Rotalipora cushmani* var. *evoluta* Sigal: 100; pl. 1, fig. 3; pl. 2, fig. 2.
1948 *Globorotalia almadensis* Cushman & Todd: 98; pl. 16, fig. 24.
1950 *Globotruncana (Rotalipora) appenninica* Renz; Mornod: 579-582 (part), text-fig. 3 (1a-c, 2a-c, not 3a-c), text-fig. 4 (not 3a-c, ? 4a-c), text-fig. 5 (not 1a-c); pl. 15, fig. 1a-c.
1951 *Globotruncana appenninica* cf. *alpha* Gandolfi; Bolli: 193; pl. 34, figs 1-3.
1952 *Globotruncana (Rotalipora) appenninica* Renz var. *typica* Gandolfi; Bolli in Church: 69, text-fig. 2.
1955 *Globotruncana (Rotalipora) evoluta* (Sigal) Küpper: 115; pl. 18, fig. 3a-c.
1955 *Globotruncana (Rotalipora) appenninica appenninica* Renz; Küpper: 114; pl. 18, fig. 2a-c.
1957a *Rotalipora* cf. *appenninica* (Renz); Bolli, Loeblich & Tappan: 41; pl. 9, fig. 5a-c.
? 1960a *Rotalipora (Thalmaninella) evoluta* (Sigal); Klaus: 810; pl. 4, fig. 3a-c.
1961b *Rotalipora evoluta* Sigal; Loeblich & Tappan: 298-299; pl. 7, figs 1-4.
1961b *Rotalipora greenhornensis* (Morrow); Loeblich & Tappan: 299-301 (part); pl. 7, figs 5, 6, not 7-10.
non 1962 *Rotalipora evoluta* Sigal; Ayala-Castanares: 26-27; pl. 4, fig. 2a-c; pl. 10, fig. 3a-c.
1964 *Rotalipora* cf. *appenninica evoluta* Sigal; Renz, Luterbacher & Schneider: 1088; pl. 8, fig. 3a-c.
non 1964 *Rotalipora evoluta* Sigal; Todd & Low: 46; pl. 2, fig. 3a-c.
1966 *Thalmaninella evoluta* (Sigal); Salaj & Samuel: 179-180; pl. 11, fig. 3a-c; pl. 12, fig. 2a-c.
1967 *Rotalipora evoluta* Sigal; Pessagno: 294-295; pl. 49, figs 12-14; pl. 53, figs 6-8; pl. 98, fig. 12.

REMARKS. This species differs from *R. appenninica* (Renz) in being about half as large and in having more angular chambers. It also possesses a more prominent umbilical shoulder than any other species in the genus. *R. evoluta* characterizes the lower part of the Lower Chalk succession and is probably ancestral to all later species of *Rotalipora*.

Loeblich & Tappan (1961b) do not give a range for *R. evoluta* in European terms, but they list the Grayson Formation as one of its more important levels of occurrence. This formation is covered by Pessagno's (1967) *R. evoluta* Subzone. However, Bandy (1967: text-fig. 7) does not agree with this range. He considers the *Rotalipora* group to have derived from *Ticinella* Reichel 1950 in the Upper Albian and *R. appenninica balernaensis* Gandolfi to be the origin for the whole plexus. *R. evoluta*, according to Bandy, was derived from *R. greenhornensis* (Morrow), and thus it must be restricted to the Upper Cenomanian. *R. evoluta* then in turn developed *R. reicheli* Mornod and *R. cushmani*. Although this evolutionary sequence more nearly agrees with the results of Klaus (1960a), it contradicts the range of *R. evoluta* as found by us. However, Salaj & Samuel (1966) use *Thalmaninella evoluta* as an indicator for the lowest part of a three-fold division of the Cenomanian.

Thus there is some variance of opinion as to the range of this species. However, in regions as far apart as Texas, the Carpathians, the Pacific Ocean, the North Atlantic Ocean and south-east England, *R. evoluta* can be used as a Lower Cenomanian indicator.

RANGE. Lower Cenomanian Zones 7-10, and Middle Cenomanian Zone 11(i).

Rotalipora greenhornensis (Morrow 1934)

(Plate 4, figs 10-12)

- 1934 *Globorotalia greenhornensis* Morrow: 199; pl. 39, fig. 1.

- 1940 *Planulina greenhornensis* (Morrow) Cushman: 37; pl. 7, fig. 1.
 1946 *Planulina greenhornensis* (Morrow); Cushman: 159; pl. 65, fig. 3a-c.
 1948 *Rotalipora globotruncanoides* Sigal: 100; pl. 1, fig. 4; pl. 2, figs 3-5.
 1948 *Thalmaninella brotzeni* Sigal: 102; pl. 1, fig. 5; pl. 2, figs 6-7.
 1948 *Globorotalia decorata* Cushman & Todd: 97; pl. 16, fig. 21.
 1950 *Globotruncana (Rotalipora) appenninica* Renz var. *typica* Gandolfi; Mornod: 582; text-fig. 9.2a-c.
 non 1950 *Globotruncana (Thalmaninella) brotzeni* Sigal; Mornod: 586; text-fig. 9.1a-c.
 1952 *Rotalipora globotruncanoides* Sigal; Sigal: 26; text-fig. 24.
 1953 *Rotalipora appenninica* (Renz); Subbotina: 159 (part); pl. 1, fig. 8a-c, not figs 5a-c, 6a-c, 7a-c; not pl. 2, figs 1a-c, 2a-c.
 1954 *Rotalipora globotruncanoides* Sigal; Hagn & Zeil: 23-25; pl. 4, fig. 7.
 non 1955 *Globotruncana (Rotalipora) globotruncanoides* Sigal; Küpper: 113; pl. 18, fig. 1a-c.
 1955 *Globotruncana (Thalmaninella)* sp. Küpper: 115; pl. 18, fig. 4a-c.
 ? 1956 *Globotruncana* n. sp., indet. Küpper: 44; pl. 8, fig. 3a-c.
 1956 *Thalmaninella greenhornensis* (Morrow) Brönnimann & Brown: 535; pl. 20, figs 7-9.
 1957 *Globotruncana (Rotalipora) appenninica* Renz; Gandolfi: 60; pl. 9, fig. 2.
 1957 *Rotalipora globotruncanoides* Sigal; Sacal & Debourle: pl. 25, ? fig. 1, fig. 3, ? fig. 11, ? fig. 15.
 non 1957a *Rotalipora brotzeni* (Sigal); Bolli, Loeblich & Tappan: 41; pl. 9, fig. 7a-c.
 non 1959 *Rotalipora globotruncanoides* Sigal; Banner & Blow: pl. 2, fig. 4.
 1960a *Rotalipora (Thalmaninella) greenhornensis* (Morrow) Klaus: 805; pl. 2, fig. 3a-c.
 ? 1960a *Rotalipora (Thalmaninella) brotzeni* Sigal; Klaus: 805; pl. 3, fig. 1a-c.
 1961b *Rotalipora greenhornensis* (Morrow); Loeblich & Tappan: 299-301 (part); pl. 7, figs 7-9, not figs 5-6, 10.
 1962 *Rotalipora greenhornensis* (Morrow); Ayala-Castanares: 28-30; ? pl. 5, fig. 3a-c; pl. 10, fig. 3a-b.
 1964 *Rotalipora greenhornensis* (Morrow); Loeblich & Tappan: C659-C661 (part), fig. 528, 4a-c, not 3a-c.
 1965 *Rotalipora greenhornensis* (Morrow); Eicher: 906; pl. 106, fig. 11.
 1966 *Thalmaninella greenhornensis* (Morrow); Salaj & Samuel: 180, text-fig. 15a-b.
 ? 1966 *Thalmaninella deeckii* (Franke); Salaj & Samuel: 179; pl. 12, fig. 4a-c.
 1966 *Rotalipora tehamaensis* Marianos & Zingula: 339; pl. 38, fig. 4a-c.
 1967 *Rotalipora greenhornensis* (Morrow); Pessagno: 295-297; pl. 50, fig. 3; pl. 51, figs 13-21; pl. 101, figs 3-4.
 1969b *Rotalipora greenhornensis* (Morrow); Douglas: 174; pl. 1, fig. 3.
 1970 *Rotalipora greenhornensis* (Morrow); Eicher & Worstell: 312; pl. 12, fig. 2a-c; pl. 13, fig. 3a-b.
 1972 *Rotalipora greenhornensis* (Morrow); Gawor-Biedowa: 83-84; pl. 9, figs 4-5.

REMARKS. This species shows raised, beaded sutures on both the spiral and umbilical sides. The chambers of the final whorl do not increase so rapidly in size as in other members of the genus. However, the marked umbilical shoulders and the raised sutures relate this form to *R. evoluta* and it is likely that *R. greenhornensis* is an Upper Cenomanian derivative of the former species. Bandy (1967) deduces a reversed relationship although Pessagno (1967) came to the same conclusions as we do. Loeblich & Tappan (1961b) figured hypotypes from the Greenhorn Formation, Hartland Shale Member, and these are remarkably similar to the specimens found in England. Eicher (1969b) records *R. greenhornensis* from the Greenhorn Formation of the western interior of the United States, indicating that it extends up as far as the Cenomanian/Turonian boundary. *R. cushmani* is also recorded in the same sequences, and while it has a closely similar range, at a few localities it extends further up the succession. In England *R. cushmani* appears earlier in the succession than *R. greenhornensis* but this may be due to several external controls; *R. greenhornensis* is more abundant in more southerly areas, so this disparity in the recorded ranges is not thought to be significant. Klaus (1960a, c) gives the range in Switzerland as Middle to Upper Cenomanian, which is not radically different from that in the British Isles. Douglas (1969b: text-fig. 4) places *R. greenhornensis* in the Upper Cenomanian and extends its range downwards slightly into the Lower Cenomanian.

As was suggested by Pessagno (1967), there is a possibility that *R. greenhornensis* is a junior synonym of *Rotalipora deeckii* (Franke 1925: 88-90; pl. 8, fig. 7a-c). The type figures of Franke's

species indicate its closeness to *R. greenhornensis*. Many European workers, more familiar with Franke's species, retain the two as separate entities. One of the latest references to *Thalmaninella deeckii* has been included in the synonymy.

RANGE. Cenomanian Zones 11(ii)–14(i) (Plenus Marls Bed 1).

Family **GLOBOTRUNCANIDAE** Brotzen 1942

Genus **GLOBOTRUNCANA** Cushman 1927

TYPE SPECIES. *Pulvinulina arca* Cushman 1926.

Globotruncana cf. *indica* (Pessagno 1967)

(Plate 3, figs 7–9)

? 1955 *Globotruncana indica* Jacob & Sastry; Gandolfi: 19; text-fig. 4, 3a–b.

1967 *Marginotruncana indica* Pessagno: 307; pl. 55, figs 3, 8–10; pl. 57, figs 6–9; pl. 98, fig. 2 (non Jacob & Sastry 1950).

REMARKS. In the upper levels of the Plenus Marls (Zone 14) rare specimens of *Globotruncana* have been found. They have been referred tentatively to *G. indica*, as described by Pessagno (1967), on the basis of the flat dorsal side and slightly inflated chambers on the ventral surface. The aperture, unlike the extraumbilical aperture of *Praeglobotruncana*, is almost umbilical, and often displays globotruncanid apertural flaps. The suggested evolution of these early globotruncanids, from *P. delrioensis* through *P. cf. hagni*, is indicated in Fig. 7 (p. 34). *G. cf. indica* is the earliest *Globotruncana* known from the British Cretaceous. Its appearance in the upper levels of the Plenus Marls (Beds 4–8), and in the upper levels of Bed C of the Cenomanian Limestones (Smith 1957a, etc.) in the south-west of England, is of major importance in the definition of the Cenomanian/Turonian boundary. Many workers regard *Globotruncana* as typical of the Turonian to Senonian interval.

RANGE. The complete range of this species is unknown, and only its first appearance is recorded here. Although rare specimens have been found in the upper levels of the Plenus Marls (Zone 14(ia)), only in the Middle Chalk can large numbers be found.

Superfamily **CASSIDULINACEA** d'Orbigny 1839

Family **ANOMALINIDAE** Cushman 1927

Subfamily **ANOMALININAE** Cushman 1927

Genus **GAVELINELLA** Brotzen 1942

TYPE SPECIES. *Discorbina pertusa* Marsson 1878.

Gavelinella baltica Brotzen 1942

(Plate 1, figs 36–38)

1942 *Gavelinella baltica* Brotzen: 50; pl. 1, fig. 7.

1962 *Gavelinella baltica* Brotzen; Jefferies: pl. 78, fig. 9a–c.

1962 *Gavelinella baltica* Brotzen; Hiltermann & Koch: 319; pl. 47, fig. 1.

1972 *Gavelinella* (*Gavelinella*) *baltica* Brotzen; Gawor-Biedowa: 125–126; pl. 17, fig. 5a–c.

REMARKS. This species is very similar to *G. intermedia* (Berthelin), from which it differs in the inflation of the final three chambers. *G. baltica* develops (Fig. 8) from *G. intermedia* in the Upper Albian, although typical forms are seen only in the Cenomanian. These earlier, more primitive, forms were described as *Anomalina rudis* (Reuss) by Chapman (1898).

RANGE. Cenomanian Zones 7–14(i) (Plenus Marls Bed 1). Rare, primitive forms have however been found in Albian/Cenomanian Zone 6a.

Gavelinella cenomanica (Brotzen 1942)

(Plate 1, figs 27, 28)

1942 *Cibicidoides* (*Cibicides*) *cenomanica* Brotzen: 54; pl. 2, fig. 2a–c.

1954 *Anomalina* (*Pseudovalvulineria*) *cenomanica* (Brotzen) var. *cenomanica* Vasilenko: 87; pl. 9, fig. 2.
 1957 *Gavelinopsis cenomanica* (Brotzen) Hofker: 321, text-fig. 370.
 1962 *Gavelinopsis cenomanica* (Brotzen); Hiltermann & Koch: 318; pl. 48, fig. 1.
 1966 *Gavelinopsis cenomanica* (Brotzen); Michael: 436; pl. 50, figs 16–17.
 1972 *Gavelinella* (*Gavelinella*) *cenomanica* (Brotzen) Gawor-Biedowa: 126–128; pl. 17, fig. 4a–c.

REMARKS. This species differs from *G. intermedia* in having a more or less marked rim around the umbilicus. There has been confusion as to the generic position of this species, attributable to the

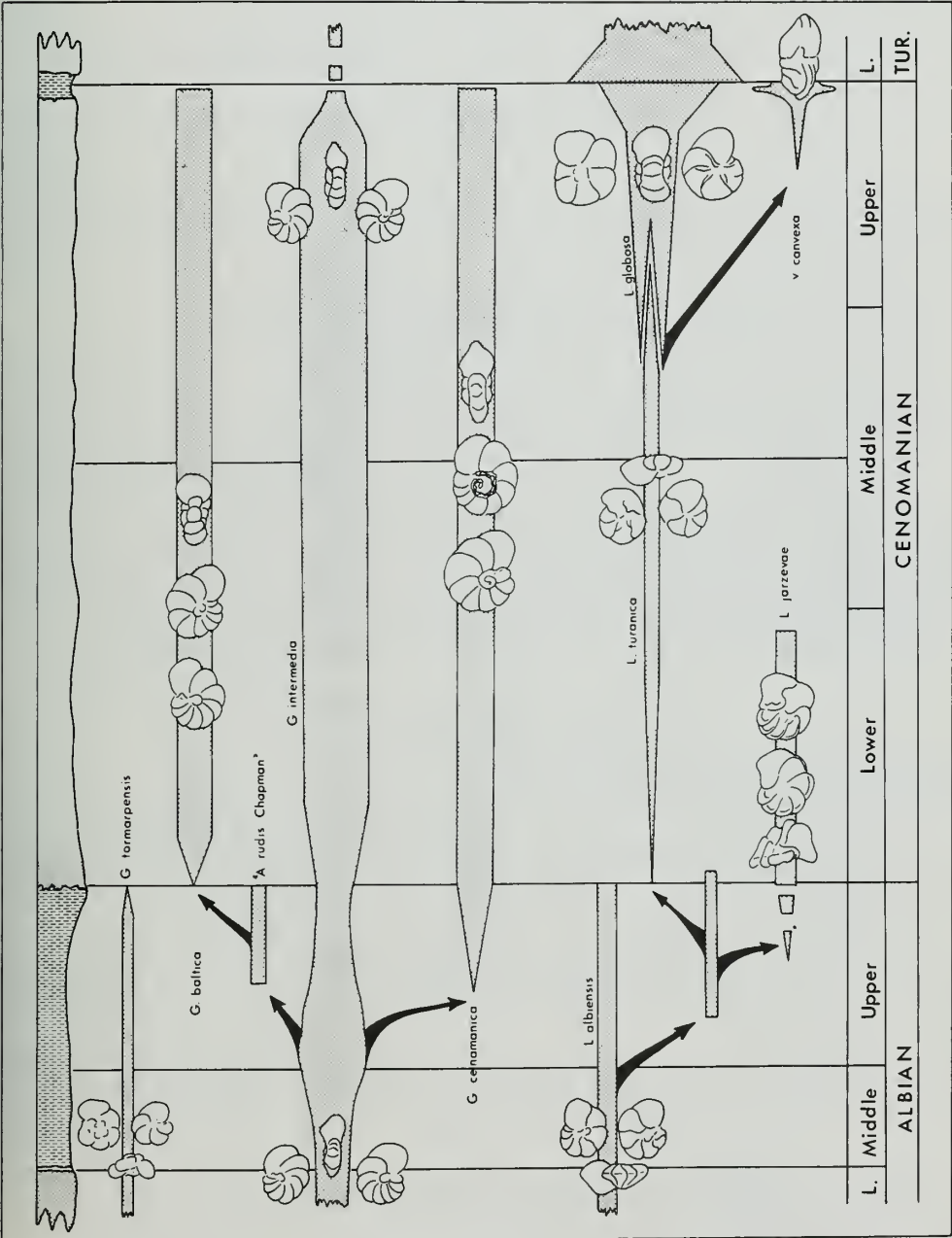


Fig. 8 Evolution of the *Gavelinella* and *Lingulogavelinella* groups.

initial description of Brotzen. In his 1942 account he calls the species *Cibicidoides* (*Cibicides*) *cenomanica*, and *Cibicides cenomanica* in the plate explanation. Hofker (1957) placed the species in *Gavelinopsis*. However, an examination of the wall structure has shown that there is a double septal wall which is in agreement with the generic description of *Gavelinella*. *G. cenomanica* can be shown, by a series of transitional forms, to have evolved from *G. intermedia* in the Upper Albian. Fuchs (1967) records specimens of *G. intermedia* from the Albian of Holland, but figures (Fuchs 1967: fig. 6a) a specimen showing a slight trace of the umbilical rim which is characteristic of *G. cenomanica*. Fuchs' specimens presumably were from a level where this transition was already well advanced.

RANGE. While primitive forms are found in Albian Zones 5–6, this species is commonly found in Albian/Cenomanian Zone 6a and Cenomanian Zones 7–14(ia) (Plenus Marls Beds 2 and 3).

***Gavelinella intermedia* (Berthelin 1880)**
(Plate 1, figs 33–35)

- 1880 *Anomalina intermedia* Berthelin: 67; pl. 4, fig. 14a–b.
 1898 *Anomalina ammonoides* Reuss; Chapman: 3; pl. 1, fig. 4.
 1942 *Gavelinella intermedia* (Berthelin) Brotzen: 52, text-fig. 18.
 1954 *Gavelinella intermedia* (Berthelin); Bartenstein: 49; pl. 1, figs 21–28.
 1954 *Anomalina* (*Anomalina*) *suturalis* Mjatluk; Vasilenko: 51; pl. 1, fig. 1.
 1954 *Anomalina* (*Anomalina*) *hostaensis* Morosowa; Vasilenko: 52; pl. 1, fig. 3.
 1954 *Anomalina* (*Anomalina*) *infracomplanata* Mjatluk; Vasilenko: 53; pl. 1, fig. 4.
 1957 *Gavelinella intermedia* (Berthelin); Hofker: 285–286, text-figs 336–337.
 1960 *Gavelinella intermedia* (Berthelin); Moullade: 138; pl. 2, figs 15–17.
 1960 *Gavelinella flandrini* Moullade: 137; pl. 2, figs 10–14.
 1965 *Gavelinella intermedia* (Berthelin); Neagu: 32; pl. 8, figs 1–2.
 1965 *Gavelinella* (*Berthelina*) *intermedia* (Berthelin); Malapris: 138–139; pls 1, 2, 5, including forms placed in *G. reussi* (Khan).
 1972 *Gavelinella* (*Berthelina*) *intermedia* (Berthelin); Gawor-Biedowa: 120–122; pl. 15, figs 7–9; text-fig. 12.

REMARKS. Berthelin's specimens were from the Gault Clay of Montcley. The species ranges through both the Albian and the Cenomanian. It is very variable in appearance, and two off-shoots from the main lineage gave rise to *G. baltica* and *G. cenomanica* in the Upper Albian.

RANGE. Albian Zone 3 to Cenomanian Zone 14(ia) (Plenus Marls Bed 3).

***Gavelinella tormarpensis* Brotzen 1942**
(Plate 1, figs 31–32)

- 1942 *Gavelinella tormarpensis* Brotzen: 52; pl. 1, fig. 6.
 1965 *Gavelinella tormarpensis* Brotzen; Malapris: 148; pl. 3, figs 1–4.

REMARKS. This very small, rounded species is one of the earliest members of the *Gavelinella* plexus recorded from the Gault Clay succession. Although common in the Middle Albian (up to Zone 4a) only rare occurrences have been reported from the Upper Albian. Specimens from south-east England are identical with specimens figured by Malapris from the type Albian.

Small specimens very closely similar to this species are recorded from the Cenomanian and Turonian, but at these higher levels a small boss or plug in the centre of the specimen gives a slightly domed appearance to the dorsal side. These individuals are probably referable to *Gavelinella minima* (Vieaux).

RANGE. Although known from the Lower Albian (Aube, France), this species has been mainly recorded from the Middle Albian Zones 3–4a. Rare specimens also have been recorded from the Upper Albian.

Genus *LINGULOGAVELINELLA* Malapris 1965

TYPE SPECIES. *Lingulogavelinella albiensis* Malapris 1965.

Lingulogavelinella globosa (Brotzen 1945)

(Plate 1, figs 12–14)

1945 *Anomalinoides globosa* Brotzen: 58; pl. 2, fig. 6a–c.

1962 *Anomalinoides globosa* Brotzen; Jefferies: 78; fig. 19a–c.

1966 *Orostella turonica* Butt: 180; pl. 3, fig. 6; pl. 4, fig. 4.

1972 *Lingulogavelinella globosa* (Brotzen) Gawor-Biedowa: 107–108; pl. 15, figs 4a–c, 5a–c.

REMARKS. A study of material from the type Turonian shows that Butt's (1966) new species *O. turonica* is identical with that described as *A. globosa* by Brotzen (1945). The new genus *Orostella*, erected by Butt to include his new species and *L. globosa*, falls within the definition of *Lingulogavelinella* Malapris (1965: 139), so *Orostella* Butt is suppressed as a junior synonym.

L. globosa is a distinctive foraminifer, recognized by the apertural flaps which cover the edges of the chambers on the ventral side, forming a star-shaped pattern. It is represented by small, atypical, forms in the Upper Cenomanian, while more characteristic individuals appear above the Cenomanian/Turonian boundary – especially in the section along the Cher Valley, Touraine, France.

RANGE. Rare in the Upper Cenomanian Zone 13, becoming more abundant in Beds 1–3 of the Plenus Marls (Zone 14(i)–(ii)). Above this level *L. globosa* is an important element of the fauna.

Lingulogavelinella globosa (Brotzen) var. *convexa* nov.

(Plate 1, figs 24–26)

1962 *Pseudovalvulineria* sp. Jefferies: pl. 78, fig. 15a–c.

DERIVATION OF NAME. The ventral side of this variety is strongly convex whereas the dorsal side can be either flat or slightly convex.

DIAGNOSIS. Similar to *L. globosa*, but strongly convex ventrally.

DETERMINATION. Test free, trochospiral and planoconvex; involute, dorsal side flat or very slightly convex, generally with 6 to 7 chambers in the final whorl visible. Convex ventral side also only displaying the last whorl. Unlike in *L. globosa* the margin of the test subangular instead of rounded. Chambers of the final whorl slightly inflated dorsally, increasing gradually in size. Sutures distinct and radial on both sides. Walls calcareous, perforate, granular, bilamellar, but usually recrystallized. Apertural flaps prominent in the final whorl and characteristic of the variety as well as the typical species.

DIMENSIONS. Average diameter 0.46 mm; average thickness 0.19 mm.

REMARKS. This variety is very similar indeed to *L. globosa*, but sufficiently distinct to warrant its elevation as a variety. Although it is superficially distinct its restricted occurrence indicates it may be an ecophenotypic variant. Several variants have been found at other very restricted stratigraphic levels, although none have any diagnostic value.

RANGE. Very rare in the Upper Cenomanian Zone 13, abundant only in Bed 1 of the Plenus Marls (Zone 14(i)).

Lingulogavelinella jarzevae (Vasilenko 1954)

(Plate 1, figs 29–30)

? 1945 *Cibicides formosa* Brotzen: 55; pl. 2, fig. 3a–c.

1954 *Cibicides* (*Cibicides*) *jarzevae* Vasilenko: 121; pl. 17, fig. 3a–c.

? 1972 *Lingulogavelinella formosa* (Brotzen) Gawor-Biedowa: 105–106; pl. 14, fig. 1a–c; text-fig. 7.

REMARKS. This distinctive species is recognized by the totally flat spiral side and the strongly elevated umbilical side. It may be the same as Brotzen's *Cibicides formosa*.

RANGE. While rare, immature specimens have been found in the Upper Albian Zones 5a–6, this species is abundant in Albian/Cenomanian Zone 6a and the Lower Cenomanian Zones 7–9. In the Lower Chalk of the south-east of England rare specimens have also been recorded from the

base of the overlying Zone 10 and from a thin band near the top of Zone 10, just below the Zone 10/Zone 11(i) boundary. It is probably an indicator of shallow-water conditions.

Superfamily **ROBERTINACEA** Reuss 1855

Family **CERATOBULIMINIDAE** Cushman 1927

Subfamily **CERATOBULIMININAE** Cushman 1927

Genus **CONORBOIDES** Hofker in Thalmann 1952

TYPE SPECIES. *Conorbis mitra* Hofker 1951.

Conorboides lamplughi (Sherlock 1914)

(Plate 1, figs 21–23)

1914 *Pulvinulina lamplughi* Sherlock: 290; pl. 19, fig. 16.

1933a *Discorbis turbo* Eichenberg: 20; pl. 1, fig. 11 (non d'Orbigny).

1950 *Lamarckina lamplughi* (Sherlock) ten Dam: 49, text-fig. 5.

1965 *Lamarckina lamplughi* (Sherlock); Neagu: 34; pl. 9, figs 6, 7.

REMARKS. Both ten Dam and Neagu place this species in the genus *Lamarckina* Berthelin. It is however very similar to *C. mitra*, and here it is referred to *Conorboides* Hofker in Thalmann.

RANGE. Rare in Middle Albian Zone 3.

Subfamily **EPISTOMININAE** Wedekind 1937

Genus **EPISTOMINA** Terquem 1883

TYPE SPECIES. *Epistomina regularis* Terquem 1883.

Epistomina spinulifera (Reuss 1862)

(Plate 4, fig. 25)

1862 *Rotalia spinulifera* Reuss: 93; figs 3a–5c.

1883 *Epistomina spinulifera* (Reuss) Uhlig: 768; pl. 7, figs 5–7.

1896 *Pulvinulina spinulifera* (Reuss) Chapman: 9; pl. 2, fig. 1a–c.

1933a *Rotalia polypoides* Eichenberg: 21; pl. 3, fig. 1a–c.

1933b *Epistomina spinulifera* (Reuss); Eichenberg: 192; pl. 22, fig. 1a–d.

1947 *Epistomina spinulifera* (Reuss); ten Dam: 28–29, figs 7a–c.

1948b *Epistomina spinulifera* (Reuss); ten Dam: 170; pl. 2, fig. 5.

1954 *Brotzenia spinulifera* (Reuss) Hofker: 182–183, text-figs 9–12.

1963 *Brotzenia spinulifera* (Reuss); Cordey: 655–656.

REMARKS. This easily recognized species characterizes the greater part of the Lower Gault Clay sequence of south-east England. The ornamentation is quite variable and a study of this feature reveals the sequence outlined below.

RANGE. This species is first recorded from Zone 2 of the Middle Albian and it extends, with increasingly strong ornamentation, through to Zone 4, where at its acme of development specimens are commonly quite massive. In Zone 4a there is some degeneration, and it is not usually recorded above that zone. Reworked material is occasionally found at higher levels in the Gault Clay succession.

Genus **HOEGLUNDINA** Brotzen 1948

TYPE SPECIES. *Rotalia elegans* d'Orbigny 1826.

Hoeglundina carpenteri (Reuss 1862)

(Plate 1, figs 15–17)

1862 *Rotalia carpenteri* Reuss: 94; pl. 13, fig. 6a–c.

1898 *Pulvinulina carpenteri* (Reuss) Chapman: 8; pl. 1, fig. 11a–c.

1948b *Epistomina carpenteri* (Reuss) ten Dam: 165; pl. 1, fig. 4.

- 1950 *Epistomina carpenteri* (Reuss); ten Dam: 50; pl. 4, fig. 3.
 1954 *Hoeglundina carpenteri* (Reuss) Hofker: 104–105; text-figs 36–37.
 1965 *Epistomina carpenteri* (Reuss); Neagu: 34; pl. 9, figs 3–4.

REMARKS. This is a very variable species, including individuals with a smooth test and ranging through to those with small spines on the chamber surfaces.

RANGE. Middle Albian Zones 3–4.

***Hoeglundina chapmani* (ten Dam 1948)**
 (Plate 1, figs 18–20)

- 1860 *Rotalia elegans* d'Orbigny; Jones & Parker: pl. 20, fig. 46.
 1898 *Pulvinulina carcolla* (Roemer); Chapman: 7; pl. 1, fig. 9.
 1898 *Pulvinulina elegans* (d'Orbigny) Chapman: 6; pl. 1, fig. 8.
 1933a *Epistomina elegans* (d'Orbigny) Eichenberg: 22; pl. 7, fig. 1.
 1948b *Epistomina chapmani* ten Dam: 166; pl. 1, fig. 5a–c.
 1950 *Epistomina chapmani* ten Dam; ten Dam: 453; pl. 4, fig. 6.
 1954 *Hiltermannia chapmani* (ten Dam) Hofker: 191–193, text-figs 27–32.
 1965 *Epistomina chapmani* ten Dam; Neagu: 34; pl. 9, fig. 5.

REMARKS. Hofker (1954) separated *Hiltermannia* (type species *H. chapmani*) from *Hoeglundina* on the basis of its smaller internal partitions. Loeblich & Tappan (1964) suggested that the relative size of these features is a specific character. Cordey (1963), for the same reason, rejected Hofker's separation of the genera *Epistomina* and *Voorthuysenia* Hofker.

RANGE. Middle Albian Zones 3–4a.

Foraminiferal zonations

A preliminary foraminiferal distribution chart for the mid-Cretaceous was published in Bruckshaw *et al.* (1961: fig. 14). While this was based on a single section (Shakespeare Cliff borehole, Dover), it was nevertheless the first completely microfaunal subdivision of the Aptian to Turonian interval in the British Isles. The zonal numbers used in the present account are based on that previous work, and because of this, only Zones 3–14 are used here. Zones 1 and 2 (a and b) refer to the Atherfield Clay and the Lower Greensand. The original distribution chart was included in a report on the Channel Tunnel Survey. Since then a second, more exhaustive, site investigation has been undertaken, and this, together with the subsequent research, has changed many of the views then held. The zonation, as used in this account, encompasses the Gault Clay (Middle and Upper Albian), the Lower Chalk (Cenomanian, approximately) and the lower levels of the Middle Chalk (Turonian).

According to Kulp (1961) this stratigraphic interval covers approximately 30 Ma, of which 20 Ma is occupied by the Cenomanian. This has been criticized as excessively long by Rubinshtein (1963) and also by Casey (*in* Harland *et al.* 1964). Rubinshtein based his objections on the thickness of sediment involved, while Casey argued that the Cretaceous should be divided into stages of equal duration. The idea that the Cenomanian Stage could occupy 20 Ma of the 72 Ma (135–63 Ma) available for the whole Cretaceous prompted Bandy (1967) to suggest that it would be more appropriate to divide the Cretaceous into three major units, instead of the more customary two. In this tripartite scheme the Cenomanian would constitute the Middle Cretaceous Substage. Whichever system of subdivision is adopted, the delimitation of the Cenomanian is of prime importance, as its base would be either the base of the Upper Cretaceous (following previous workers) or the base of the Middle Cretaceous (following Bandy).

The value of planktonic foraminifera for correlation has been discussed at length by Bandy (1964, 1967). In the Upper Cretaceous, and even more in the Cenozoic, there is such a variety of planktonic foraminifera that it has been possible to formulate accurate zonations based on this group. In the Lower Cretaceous, however, there are few genera and species which can be used for correlation. In most cases these belong to primitive, long-ranging groups. While this is true of the Albian, there are changes in the Cenomanian, when planktonic foraminiferal evolution began to

accelerate, and this continued throughout the Cenomanian with the appearance of more typically Upper Cretaceous lineages. The rapid diversification of planktonic foraminifera during the Cenomanian, however, does not allow the identification of more than two zones. The Albian cannot, at the present time, be divided into zones and a single population identifies it.

Because of the deficiency in planktonic foraminifera, benthonic species have been used in conjunction with them in the compilation of another zonal scheme for local correlation. This, permitting correlation within the Anglo-Paris Basin, can be compared with other more distant successions on the basis of its planktonic content. Apart from the preliminary zonal scheme of 1961, which also was based on both benthonic and planktonic species, there has been no attempt at a comprehensive microfaunal analysis of the mid-Cretaceous in Great Britain. Only two previous works, Williams-Mitchell (1948) and Barnard & Banner (1953), were concerned with correlation, although others, e.g. Chapman (1891-98), Barr (1962), have documented the fauna from selected horizons. Unfortunately both used previously-defined macropalaontological zones as a foundation and neither produced a workable system of microfaunal subdivision. It is likely that this lack of success deterred further attempts at a solution of this problem. The present authors' approach has been to collect samples at regular intervals throughout the succession under investigation, without reference to any other faunal controls. The result has been the detection of the actual microfaunal boundaries, which can now be related to any macrofaunal scheme produced for the same sequence.

a. Planktonic zonal scheme

Williams-Mitchell (1948), in his analysis of the zonal value of the foraminifera, used benthonic species primarily, although two planktonic species (*Globigerina portsdownensis* Williams-Mitchell and *Rotalipora turonica* Brotzen) were described from the Cenomanian. This is the only use made of planktonic foraminifera in the British mid-Cretaceous to date. Although the paucity of genera allows the identification of only four zones, these nevertheless can be used for international correlation. The planktonic species involved, and the zonal analysis, are shown in Fig. 9.

(i) *Hedbergella delrioensis*/*H. infracretacea* Zone – Middle & Upper Albian.

Type section: Shakespeare Cliff Borehole, Dover, 1958 (544'0" (base of Lower Gault Clay) to 403'1") (165.81-122.86 m).

Hedbergella is dominant throughout this interval. *Heterohelix*, *Guembelitria* and *Globigerinelloides* are also represented. None of the more customary Tethyan genera (*Ticinella* Reichel and *Planomalina* Loeblich & Tappan) are present, and the British faunas cannot be equated with some of the other European successions. Bandy (1967) also recognized the paucity of planktonic species at this level when he described the Lower Cretaceous (Neocomian – Albian) as characterized by a primitive, planktonic fauna. Present research does not extend below the Gault Clay, and it is impossible to place the lower boundary of this zone.

Hedbergella delrioensis – common at most levels

H. infracretacea – common at most levels

H. planispira – common at most levels

H. washitensis – rare, only seen at the Middle/Upper Albian boundary

Heterohelix moremani – common at most levels in the Upper Albian

Guembelitria harrisi – common at most levels in the Upper Albian

Globigerinelloides bentonensis – generally rare, although some concentrations are found, particularly in the Upper Albian

(ii) *Rotalipora evoluta*/*Praeglobotruncana delrioensis* Zone – Lower & Middle Cenomanian.

Type section: Shakespeare Cliff Borehole, Dover, 1958 (403'1" to 270'0") (122.86-82.29 m).

The base of this zone is marked by the appearance of keeled, planktonic foraminifera, and is a readily recognizable horizon. As *R. evoluta* is generally rare, *P. delrioensis* is the more usual indicator encountered in the British successions, although even this species is uncommon (less than 5% of the total 60/30 grain size fraction) at this level. The *Hedbergella* lineage is still dominant

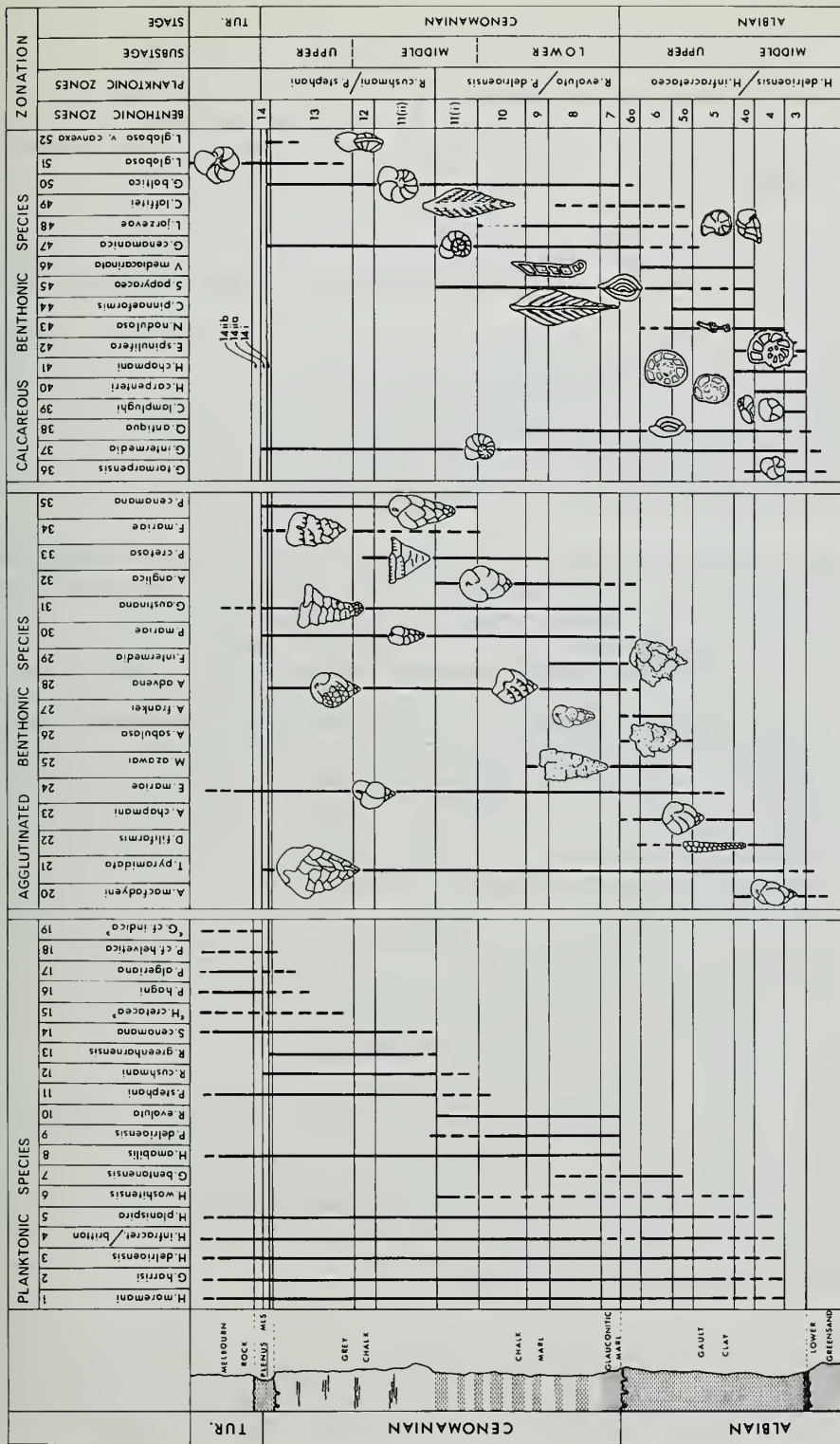


Fig. 9 Fóraminiferal zonation of the mid-Cretaceous (M. Albian - L. Turonian).

numerically. *H. amabilis* has appeared at the base of the zone and *H. brittonensis* replaces *H. infracretacea*. In the upper levels of the zone species more characteristic of the overlying one (iii) begin to appear, although only in small numbers. The early transitional forms between *P. delrioensis* and *P. stephani* are the most conspicuous although primitive forms of *Rotalipora cushmani* have also been recorded. The uppermost few metres of this zone are characterized by the occurrence of *Hedbergella washitensis* in much larger numbers than at any previous level.

Hedbergella amabilis – occurs throughout the zone in small numbers

H. brittonensis – occurs throughout the zone in small numbers

H. delrioensis – common throughout the zone

H. planispira – common throughout the zone

H. washitensis – rare, except in the top few metres of the zone, and at a few scattered horizons at its base

Praeglobotruncana delrioensis – occurs throughout the zone in small numbers

P. stephani – rare, early forms only appear late in the zone

Rotalipora evoluta – rare throughout the zone

R. cushmani – extremely rare, only found late in the zone

Globigerinelloides bentonensis – very rare, but occurs throughout the zone

Heterohelix moremani – common throughout the zone

Guembelitra harrisi – common throughout the zone

(iii) *Rotalipora cushmani*/*Praeglobotruncana stephani* Zone – Middle & Upper Cenomanian.

Type section: Shakespeare Cliff Borehole, Dover, 1958 (270'0" to 143'0") (82.29–43.58 m).

This zone is characterized by the occurrence of very distinctive (*Rotalipora cushmani* and *Praeglobotruncana stephani*) species of planktonic foraminifera, usually in abundance. The total planktonic population in the 60/30 grain size fraction has been found, at certain levels, to exceed 60% of the total, of which a single species (*R. cushmani*) comprises 40%. This general abundance of the planktonic fauna is almost as indicative of the Upper Cenomanian as the species themselves. *R. greenhornensis* is also found throughout this zone although it disappears just before *R. cushmani*. In the upper levels more complex members of the *Praeglobotruncana* group appear, including *P. algeriana*, *P. cf. helvetica* and *P. hagni*. These show twin keels unlike the typically Cenomanian species. However, they are very rare and only become abundant in the lower levels of the overlying zone.

Hedbergella amabilis – common throughout the zone

H. brittonensis – common throughout the zone

'*H. cretacea*' – very rare, only seen late in the zone

H. delrioensis – abundant throughout the zone

H. planispira – common throughout the zone

Praeglobotruncana algeriana – very rare, only seen late in the zone

P. delrioensis – seen throughout the zone in small numbers

P. hagni – very rare, only seen late in the zone

P. cf. helvetica – very rare specimens found very high in the zone

P. stephani – abundant throughout the zone

Rotalipora cushmani – abundant throughout the zone

R. greenhornensis – seen throughout the zone, although rarely common

Schackoina cenomana – uncommon, but occurring throughout the zone

Globigerinelloides bentonensis – uncommon throughout the zone

Guembelitra harrisi – abundant throughout the zone

Heterohelix moremani – abundant throughout the zone

(iv) *Praeglobotruncana* spp. Zone – Lower Turonian.

Type section: Shakespeare Cliff Borehole, Dover, 1958 (base of zone at 143'0") (43.58 m).

This zone is defined only in as far as its appearance automatically sets the upper limit of the Cenomanian. A full discussion of the Turonian foraminifera is available elsewhere (Owen 1970),

and only passing reference will be made to the species which characterize these levels. The boundary between this zone and the preceding one is the most distinctive in the Cretaceous system, and falls at the base of Jefferies' (1962, 1963) Plenus Marls Bed 4. The *Rotalipora* fauna gives way to a typically twin-keeled *Praeglobotruncana* and *Globotruncana* fauna, and close below this level (base of Jefferies' Plenus Marls Bed 2) there are sweeping changes in the benthonic population. *P. algeriana* and *P. hagni*, while appearing in the Upper Cenomanian, only become common in this zone, and in abundance are diagnostic of it. The zone has not been fully investigated and only a list of the species encountered will be given.

Hedbergella amabilis, *H. brittonensis*, '*H. cretacea*', *H. delrioensis*, *H. planispira*, *Schackoina cenomana*, *Guembelirria harrisi*, *Heterohelix moremani*, '*Globotruncana* cf. *indica*', *Praeglobotruncana algeriana*, *P. hagni*, *P. cf. helvetica*, *P. stephani*.

b. Benthonic zonal scheme

Although a wide range of species is used, they belong mainly to three groups. The most important belong in the *Arenobulimina* – *Flourensina* lineage (Fig. 3, p. 11), which has already been discussed in detail. The *Gavelinella* and *Lingulogavelinella* lineages (Fig. 8, p. 47), while of less diagnostic value, are very useful. The full zonation, with all the planktonic and benthonic species, is shown in Fig. 9, p. 53. This diagram, with the comments in the taxonomic section, makes detailed description unnecessary. Comments of a very general nature are added below.

ZONE 3: Middle Albian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 544'0" to 524'6" (165.81–159.87 m). Concurrent Range Zone: *Conorboides lamplughi*/*Epistomina spinulifera*.

The fauna of this zone is rather limited, although the species are all very distinctive. *C. lamplughi* is not found above it, but *Gavelinella tormarpensis*, *Hoeglundina chapmani*, *H. carpenteri*, *E. spinulifera*, and *Arenobulimina macfadyeni* persist to higher levels.

ZONE 4: Middle Albian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 524'0" to 487'3" (159.72–148.51 m). Concurrent Range Zone: *Hoeglundina carpenteri*/*Dorothia filiformis*.

This zone contains large, highly ornamented specimens of *Epistomina spinulifera*, often in flood abundance, associated with *H. carpenteri*, *H. chapmani* and *D. filiformis*, which continues above.

ZONE 4a: Middle to Upper Albian (transitional). Type section: Dover, No. 1 (Aycliff) (TR 294395) – 487'3" to 475'0" (148.51–144.78 m). Concurrent Range Zone: *Epistomina spinulifera*/*Citharinella pinnaeformis*.

The stratigraphic position of this very thin zone will not be known until investigation of the ammonite fauna has been completed. It contains the typically Upper Albian *Arenobulimina chapmani*, *Nodobacularia nodulosa*, *C. pinnaeformis* and *Spiroloculina papyracea* in association with poorly developed and rather rare specimens of *E. spinulifera*. The zone is not always present, its fauna is rather uneven, and it is possible that the specimens of *E. spinulifera* may be derived.

ZONE 5: Upper Albian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 475'0" to 416'0" (144.78–126.80 m). Assemblage Zone: *Citharinella pinnaeformis*.

Arenobulimina chapmani is the dominant species throughout this zone. *C. pinnaeformis* is also present but specimens are fragmentary and never abundant. Other typical species include *Tritaxia pyramidata*, *Nodobacularia nodulosa*, *Dorothia filiformis*, *Spiroloculina papyracea*, *Quinqueloculina antiqua* and the first, rather rare *EGgerellina mariae*.

ZONE 5a: Upper Albian. Type section: Channel Tunnel Site Investigation (1964–65) Borehole No. R.005 – 292'6" to 289'0" (89.15–88.09 m). Concurrent Range Zone: *Citharinella pinnaeformis*/*Arenobulimina sabulosa*.

The appearance of the quadriserial, highly rugose *A. sabulosa*, and *Marssonella ozawai*, in association with *C. pinnaeformis* (which becomes rare at the top of its range) typifies this zone. Other important species are *Tritaxia pyramidata*, *Arenobulimina chapmani*, and *Gavelinella intermedia*. This zone is always very thin, and is often missing.

ZONE 6: Upper Albian. Type section: Dover, No. 1, (Aycliff) (TR 294395) – 414'0" to 403'1" (126.19–122.86 m). Concurrent Range Zone: *Vagulina mediocarinata*/*Arenobulimina frankei*.

Where Zone 6a is missing *A. frankei* is restricted to this zone. *A. sabulosa* and *A. chapmani* are the dominant species, usually associated with *Marssonella ozawai* and *Tritaxia pyramidata*. *V. mediocarinata* does not persist above this zone. *Dorothia filiformis* and *Nodobacularia nodulosa* are very rare and not always present.

ZONE 6a: Upper Albian to Lower Cenomanian (transitional). Type section: Channel Tunnel Site Investigation (1964–65) Borehole No. R.005 – 289'0" to 246'6" (88.09–80.62 m). Concurrent Range Zone: *Arenobulimina sabulosa*/*Flourensina intermedia*.

This zone, with its distinctive fauna containing large specimens of *Citharinella laffitei*, yields both Upper Albian and Cenomanian benthonic species in addition to transitional forms. Typically Albian species: *A. chapmani*, *A. sabulosa*, *A. frankei*, etc. (in lower part of zone). Typically Cenomanian species: *A. advena*, *F. intermedia*, *Gaudryina austinana*, *Gavelinella cenomanica*, etc. (in the upper part of the zone). Intermediate forms: *A. chapmani*/*A. advena*, *A. sabulosa*/*A. anglica*, *G. intermedia*/*G. cenomanica*, and *A. frankei*/*Plectina mariae*. Although planktonic species are associated with the benthonic population no keeled forms have ever been found. The latter first appear in Zone 7, suggesting that Zone 6a is late Upper Albian in age.

Zone 6a has a peculiar geographical distribution. It has been found only in boreholes in the north-western part of the English Channel between Dover and Cap Blanc Nez, in the Upper Greensand exposures in Surrey between Godstone and Betchworth, and possibly in the Fetcham Mill Borehole. Elsewhere it is cut out by the Albian/Cenomanian non-sequence. In the Channel it occurs as a small sedimentary cycle, rich in white mica and sharply truncated by the overlying 'Glaucinitic Marl'. The base of the cycle is lithologically almost indistinguishable from the latter, but where the cycle is thick (i.e. off Dover) the two are separated by micaceous marls rich in disseminated glauconite.

No ammonites have been found in Zone 6a, but its probably very late Upper Albian age and restricted distribution suggest that it may be equivalent to the whole or a part of the *Stoliczkaia dispar* Zone.

ZONE 7: Lower Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 403'1" to 401'9" (122.86–122.45 m). Concurrent Range Zone: *Plectina mariae*/*Bulbophragmium aequale folkestoniensis* (Chapman).

This zone contains the first, purely Cenomanian benthonic fauna, dominated by *Arenobulimina advena*, *Flourensina intermedia*, *Marssonella ozawai*, *Plectina mariae*, *Gavelinella baltica*, *Lingulogavelinella jarzevae*, and very large, coarsely agglutinated Lituolacea (i.e. *B. aequale folkestoniensis* (Chapman)). This zone coincides with the 'Glaucinitic Marl' and the abundance of the large Lituolacea is facies-controlled. In the absence of the typical lithology Zones 7 and 8 are not easily separated.

ZONE 8: Lower Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 401'9" to 362'10" (122.45–110.59 m). Concurrent Range Zone: *Flourensina intermedia*/*Arenobulimina anglica*.

F. intermedia in association with abundant *A. anglica* characterize this zone. *A. advena*, *Marssonella ozawai*, *Tritaxia pyramidata* and other agglutinated species continue up from below but *B. aequale folkestoniensis* is replaced by the less coarsely agglutinated *B. aequale aequale* (Reuss). Other common species include *Eggerellina mariae*, *Plectina mariae*, *Spiroloculina papyracea*, *Gavelinella intermedia*, *G. cenomanica* and *G. baltica*.

ZONE 9: Lower Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 362'10" to 337'0" (110.59–102.72 m). Concurrent Range Zone: *Marssonella ozawai*/*Pseudotextulariella cretosa*.

In Zone 9 *M. ozawai* and *Lingulogavelinella jarzevae* are found in association with *P. cretosa*.

Flourensina intermedia is absent, but *Tritaxia pyramidata*, *Eggerellina mariae*, *Arenobulimina advena*, *A. anglica*, *Gavelinella intermedia*, *G. cenomanica* and *G. baltica* continue up from below.

ZONE 10: Lower Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 337'0" to 290'0" (102.72–88.39 m). Assemblage Zone: *Pseudotextulariella cretosa*.

Zone 10 yields *Tritaxia pyramidata*, *Eggerellina mariae*, *Arenobulimina advena*, *Plectina mariae*, *Gaudryina austinana*, *Pseudotextulariella cretosa*, *Gavelinella intermedia*, *G. cenomanica* and *G. baltica*, but no *Marssonella ozawai* or *P. cenomana*. *Lingulogavelinella jarzevae* reappears in a thin band near its top in south-east England.

ZONE 11(i): Middle Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 290'0" to 270'0" (88.39–82.30 m). Concurrent Range Zone: *Arenobulimina anglica*/*Plectina cenomana*.

The beginning of the Middle Cenomanian is characterized by the appearance of *P. cenomana*, although the remainder of the fauna remains unchanged. In this zone this species is in association with *Spiroloculina papyracea* and *A. anglica*.

ZONE 11(ii): Middle Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 270'0" to 225'0" (82.30–68.58 m). Assemblage Zone: *Plectina cenomana*.

This zone is differentiated from Zone 11(i) primarily on planktonic foraminifera. Its base is the mid-Cenomanian non-sequence, and with the onset of deeper water conditions *Arenobulimina anglica* and *Spiroloculina papyracea* disappear. The upper limit of the zone nearly coincides with the disappearance of *Pseudotextulariella cretosa*, which finally dies out just above the base of the very thin Zone 12.

ZONE 12: Middle Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 225'0" to 220'0" (68.58–67.06 m). Acme Zone: *F. mariae*.

Zone 12 is characterized by the appearance of large and abundant specimens of the very distinctive *Flourensina mariae* (total range from Zone 11(ii)–14(i)). *Pseudotextulariella cretosa* dies out just above its base and there is evidence of a return to shallow water conditions at this level. The fauna is sometimes abraded and in some sections this zone is terminated above by a weakly developed non-sequence.

ZONE 13: Upper Cenomanian. Type section: Dover, No. 1 (Aycliff) (TR 294395) – 220'0" to 147'0" (67.06–44.81 m). Assemblage Zone: *Lingulogavelinella globosa*.

Zone 13 yields an association of *Tritaxia pyramidata*, *Eggerellina mariae*, *Arenobulimina advena*, *Plectina mariae*, *Gaudryina austinana*, *Flourensina mariae*, *P. cenomana*, *Gavelinella intermedia*, *G. baltica* and *G. cenomanica*, with *L. globosa* which is not found below.

ZONE 14: Upper Cenomanian/Lower Turonian. This zone coincides with the *Actinocamax plenus* marls of Jefferies (1962, 1963). We are in agreement with many of the conclusions of Jefferies, and only disagree with the overall placing of the marls in the Turonian Stage. The decision to place the Cenomanian/Turonian boundary within this marl unit will be discussed in detail in a later section. The division of the Plenus Marls into eight lithologically and faunally distinctive beds has been corroborated. The recognition of an important erosion surface below the Plenus Marls, as well as at four levels within the sequence, agrees with the present research although we would attach more importance to the pre-Bed 4 erosion surface and less to the sub-Plenus Marls erosion surface.

Zone 14 can be split into two distinct units (14(i) and 14(ii)) on the basis of the marked faunal change at the base of Bed 2. (See Fig. 9, p. 53.)

ZONE 14(i): Upper Cenomanian. Type section: Merstham Greystone Limeworks (TQ 295542). Bed 1 of Jefferies (1962, 1963). Acme Zone: *Lingulogavelinella globosa* var. *convexa*.

This zone contains the same typically Cenomanian species as Zone 13 accompanied by very abundant *L. globosa* var. *convexa* and *Arenobulimina depressa* (Perner) (see Fig. 3, p. 11).

ZONE 14(ii): Upper Cenomanian and Lower Turonian. Type section: Merstham Greystone Limeworks (TQ 295542). Base of Zone at base of Bed 2 of Jefferies (1962, 1963). Assemblage Zone: *Arenobulimina preslii* (Reuss).

Zone 14(ii) contains none of the typically Cenomanian species and the benthonic fauna as a whole becomes less diverse. Assemblages rich in internally subdivided members of the genus *Arenobulimina* are replaced by those containing the internally simple *A. depressa*, *A. truncata* (Reuss) and *A. preslii* (see Fig. 3). *Eggerellina mariae*, *Gaudryina austinana* and *Lingulogavelinella globosa* persist up from below, and often form appreciable proportions of the assemblage.

c. Combined planktonic and benthonic zonal scheme; subdivision of Zone 14

Whereas the zonation based on planktonic foraminifera provides a firm basis for long-range correlation and the delimitation of stage boundaries it is too coarse for the solution of many correlation problems. The benthonic zonation is much finer, but some of the subdivisions are poorly defined and admittedly unsatisfactory. The use of both in conjunction makes the zonal boundaries more definitive where coincident and permits additional subdivision where they are not. In particular Zone 14(ii) can be subdivided further.

ZONE 14(iia): Upper Cenomanian. Type section: Merstham Greystone Limeworks (TQ 295542). Beds 2 and 3 of Jefferies (1962, 1963). Assemblage Zone: *Arenobulimina preslii*/*Rotalipora cushmani*.

This zone is characterized by the association of Cenomanian planktonic species (*R. cushmani*, etc.) with a benthonic association more typical of the Turonian (*A. depressa*, *A. truncata*, *A. preslii*, *Eggerellina mariae*, *Tritaxia tricarinata* (Reuss), *Gaudryina austinana*, *Lingulogavelinella globosa*, etc.).

ZONE 14(iib): Lower Turonian. Type section: Merstham Greystone Limeworks (TQ 295542). Base of zone at base of Bed 4 (Jefferies 1962, 1963). Assemblage Zone: *Arenobulimina preslii*/*Praeglobotruncana hagni*.

Zone 14(iib) contains the same benthonic association as Zone 14(iia) with abundant Turonian planktonic species ('*Globotruncana* cf. *indica*', *P. hagni*, *P. algeriana*, etc.).

Although the subdivisions of Zone 14 proposed here are easily recognizable, we consider their use inadvisable in the arguments set out herein. The position of the Cenomanian/Turonian boundary and the Cenomanian stratigraphy of south-west England is more easily clarified using the synchronous but more finely drawn Plenus Marls Bed number sequence of Jefferies (1962, 1963).

Determination of stage boundaries

Following the standard practice of defining only the base of a stage, two such levels are discussed.

a. Base of the Cenomanian Stage

The type area for the Cenomanian, according to d'Orbigny (1847, 1850), is the area of Sarthe in western France. Here the majority of workers have drawn the base of the stage at the base of the 'argille glauconieuse à minerai de fer' (Guillier 1886, Delaunay 1934, Sornay 1957, Hancock 1959 and Juignet 1968). Hancock (1959) regards this horizon as the base of the 'zone à *Mantelliceras mantelli*'. Kennedy (1969) divided the Lower Cenomanian (Zone of *M. mantelli*) into the three assemblage subzones, of *Hypoturrilites carcitanensis*, *Mantelliceras saxbii* and *M. dixonii*. The appearance of the *H. carcitanensis* assemblage fauna would therefore mark the base of the Cenomanian in the British successions.

The Lower Cenomanian sands in the Sarthe are decalcified and direct microfaunal studies have unfortunately been attempted only recently. No results are available, and indeed the chance of a large fauna being found is very slight.

In the south-east of England Kennedy (1969) records the occurrence of the *H. carcitanensis* assemblage in several localities. While this horizon is poor in the Folkestone/Dover section, Kennedy (1969 : 474) notes 'ammonites, probably of *H. carcitanensis* assemblage, range up to 2r, but completely diagnostic forms are absent. 2v has yielded what seems to be a *Mantelliceras saxbii* assemblage ammonite'. While the weakness of the evidence for a *H. carcitanensis* assemblage undoubtedly troubled Kennedy he still (1969 : fig. 16) correlated it with the excellent *H. carcitanensis* assemblage from Beddingham, Sussex.

As the microfaunal control is more satisfactory at Dover and Folkestone the base of the Glauconitic Marl at East Wear Bay has been taken as the base of the Cenomanian. The main elements of the microfauna taken as being indicative of this level are the appearance of the *Rotalipora evoluta*/*Praeglobotruncana delrioensis* Zone fauna, and the appearance of large numbers of *Arenobulimina advena* (replacing *A. chapmani*) and *Flourensina intermedia* (replacing *A. sabulosa*) as the dominant elements of the fauna. The most important feature of this faunal turnover is the appearance of the keeled planktonic foraminifera. The majority of recent workers – Pessagno (1967), Bandy (1967) and Douglas (1969a, b) – consider the appearance of the *Rotalipora* fauna as indicative of this level. The base of the Cenomanian in Great Britain is therefore taken as the base of the Glauconitic Marl in East Wear Bay (Folkestone), and can be recognized faunally as the base of the *R. evoluta*/*P. delrioensis* Zone (base of Zone 7 on the benthonic scheme).

b. Base of the Turonian Stage

Unlike the Cenomanian, this boundary has been the source of much confusion. The suggestions of Bandy (1967) and Pessagno (1967) have been largely ignored as they were not based on the type area, and lacked macrofaunal control. Work is still in progress on the fauna of the basal Turonian of the type area, and only an outline of the problem and some preliminary results can be given here.

One of the most recent works on the Turonian is that of Butt (1966), who proposed a complete succession of lithostratigraphic units based on the Cher Valley. This largely followed the work of Lecointre (1959) even though he was at some variance with many other workers in this field. It is necessary therefore to trace events from the initial definition of the stage, and the following is a short summary of the relevant work on the type sections of the Touraine (and the Sarthe).

In 1842 d'Orbigny erected the Turonian Stage with the comments

... Je propose de désigner à l'avenir l'étage que m'occupe (craie chloritée, glauconie crayeuse, craie tuffeau, et grès verts) sous le nom de Turonien, de la ville de Tours (Turones) ou de la Touraine (Turonion) situées sur ces terrains.

In 1847 d'Orbigny himself redefined the stage, erecting the Cenomanien Stage to include the lower part of his previously defined Turonien. The section of the Fréteville Chalk (Butt 1966) and the succession in the Cher Valley was known to such workers as de Grossouvre (1889, 1901) and Faupin (1908), but it was Lecointre (1959) who first defined the type section of the Turonian Stage within this area. Immediately prior to this work, however, Sornay (1957) had defined the base of the Turonian as the base of the *Inoceramus labiatus* (or *Mammmites nodosoides*) Zone. Lecointre (1959 : 421), while recognizing that this faunal association was 'characteristic' of the 'craie marneuse à chaux hydraulique', included, below this level – and still within the Turonian – the 'marnes à *Terebratella carentonensis*', the 'marnes à *Ditrupea deformis*' and the 'Sables de Bousse'. Unfortunately the text-figure in which this relationship was explained does not really correspond to the text (Lecointre 1959 : 419–420), where he describes the lateral variations in facies recorded at this level. The following is a short abstract from his list of important variations (Fig. 10).

1. La craie marneuse sans silex occupe toute la surface de la Touraine *sensu lato* et varie: parfois moins argileuse, plus sèche, parfois au contraire donnant sans mélange de la bonne chaux hydraulique...

Par sa base, elle est susceptible de varier considérablement. Les faciès arénacés du Cénomanien peuvent survivre à cette époque et se prolonger dans la base du Turonien, sable à *Catopygus* de Bousse, marnes à *Terebratella carentonensis*, marnes à *Ditrupea deformis* de l'Anjou et du Maine.

Aucune Ammonite n'a été recueillie dans ces niveaux, aussi peut-on soutenir qu'elles appartiennent au Cénomanien (de Grossouvre 1901, p. 766).

It seems that these distinctive facies of the basal Turonian were regarded by Lecoivre as local variations in the area immediately adjacent to the type sections. Butt (1966) only studied a single section in the Cher Valley and did not even mention the stratigraphic position of these local variations. His description of the foraminifera of the Frétevou Chalk ('craie marneuse sans silex') does however eliminate many of the problems facing micropalaeontologists. *Rotalipora* spp. was

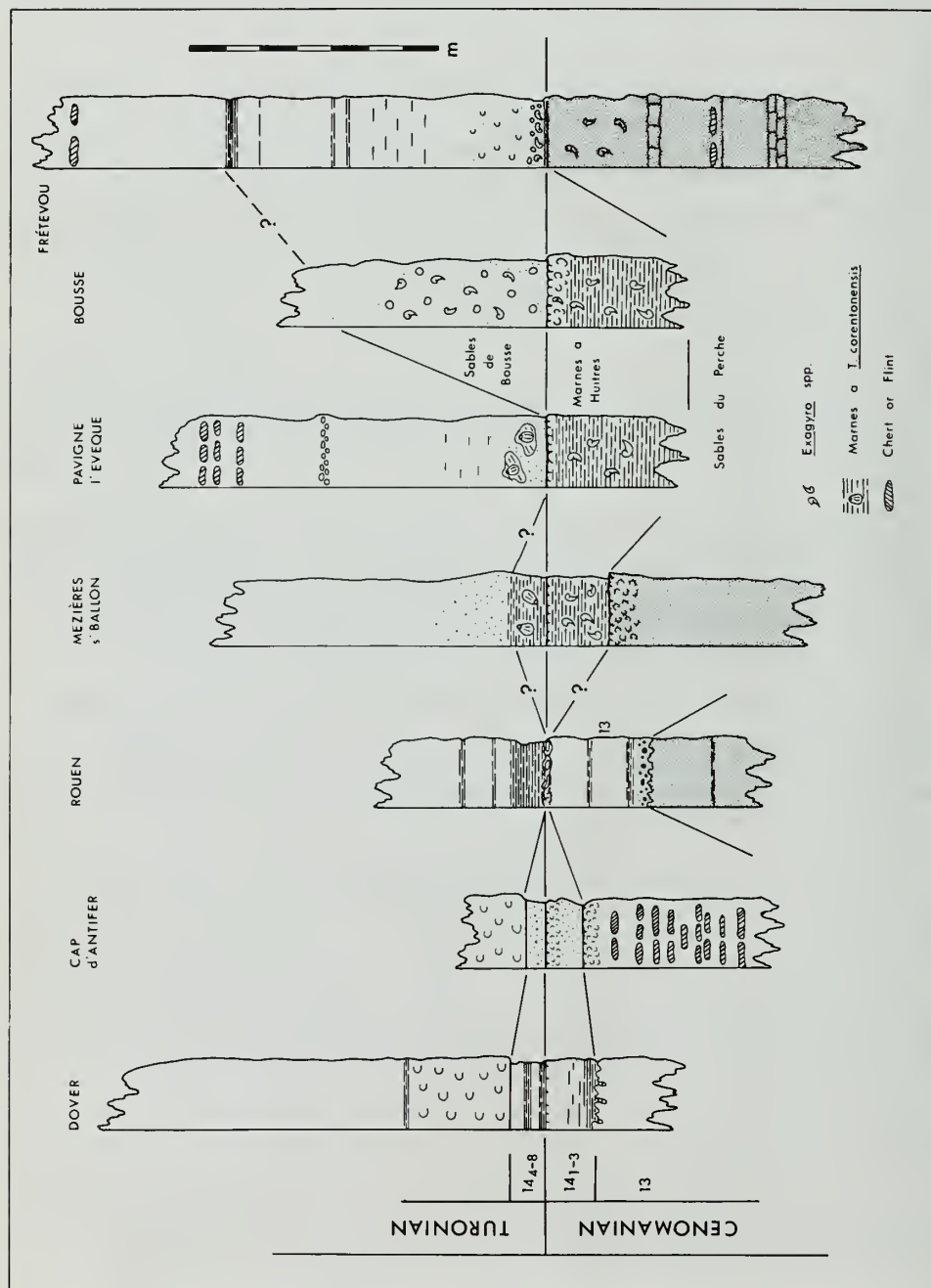


Fig. 10 The Cenomanian/Turonian boundary in southern England and northern France. The nodular chalk near the base of the Turonian in the Dover succession is the local equivalent of the Melbourn Rock.

not recorded by Butt from the Frétevou Chalk nor has it been found by us in any previously described 'Turonian' chalk, from either the type area or southern England. This confirms Marks' (1967) contention that the *Rotalipora* fauna is characteristically Cenomanian and the Turonian age of beds from which *R. cushmani* (or *R. turonica*) has been recorded is suspect. Marks (1967: table 3) indicated the previously recorded ranges of *R. cushmani*. The appearance of this species in the mid-Cenomanian as recorded by Marks, and its continuation to the Cenomanian/Turonian boundary as recorded by Malapris & Rat (1961a, b), is in agreement with the British successions.

The planktonic foraminifera recovered from the Frétevou Chalk by Butt (1966) and ourselves include *Praeglobotruncana stephani*, *P. hagni* and *Hedbergella delrioensis*. This association, together with abundant *Lingulogavelinella globosa*, has only been recorded from:

1. the 'marnes à *Terebratella carentonensis*',
2. the 'Sables de Bousse',
3. the Plenus Marls (Beds 4–8) and
4. the *Praeglobotruncana roddai* (? = *P. hagni*) Subzone of northern California as described by Douglas (1969b), which occupies a thickness of several hundred feet.

The correlation scheme shown in Fig. 9 (p. 53) summarizes the present state of microfaunal knowledge of this succession, and although work is not complete a pattern is beginning to emerge. The main feature is the reported first appearance of *Inoceramus labiatus* at a horizon above the Plenus Marls (W. J. Kennedy, *pers. comm.*). This agrees with Lecointre's (1959) observation that *I. labiatus* appears above the base of the 'craie marneuse sans silex' in the type section. Describing the Frétevou Chalk succession, Lecointre includes a bed of 'craie marneuse grise à *Rhynchonella cuvieri* d'Orbigny' between the beds of 'craie marneuse blanche micacée à nombreux *Inoceramus labiatus* Brongniart' and the underlying oyster-bearing Cenomanian glauconitic sands. The thickness of this *I. labiatus*-free chalk is not given and the field work of one of us (M. B. H.) on this section gave no reliable figure. While *I. labiatus* may characterize the Lower Turonian, it is not the best species with which to define the base of the Turonian in the type section.

The planktonic microfauna of the basal Frétevou Chalk includes:

Praeglobotruncana algeriana – uncommon

P. hagni – very common

P. stephani – abundant

Hedbergella delrioensis – abundant

The *Rotalipora* fauna is not present and one only can deduce that this genus is not represented in the Turonian. As the above-listed fauna is also recorded from the 'marnes à *T. carentonensis*' and the 'Sables de Bousse', Lecointre was correct in suggesting that these locally-developed facies are lateral equivalents of the basal Turonian. The rather poor benthonic fauna of the Frétevou Chalk corresponds very well with that recorded from the Plenus Marls (Beds 4–8). The base of the Turonian is therefore drawn at the erosion surface between Beds 3 and 4 of the Plenus Marls sequence. This restricts the *Rotalipora* fauna to the Cenomanian, as suggested by Bandy (1967), Pessagno (1967), Marks (1967) and Douglas (1969b). The change from the *Praeglobotruncana*/*Rotalipora* fauna of the Cenomanian to the *Praeglobotruncana*/*Globotruncana* fauna of the Turonian can be recognized all over the world and it is suggested that the base of the Plenus Marls Bed 4 is the most acceptable level for such an important boundary.

The mid-Cenomanian non-sequence

The placing of the Cenomanian/Turonian boundary where stated above permits accurate correlation of the British successions with those overseas. The section provided by Eicher (1969b) from the western interior of the United States is one of the most suitable for detailed comparison (Fig. 11). The most interesting feature is the sudden change from a predominantly benthonic population to a largely planktonic one within the mid-Cenomanian. Although the actual percentage change is not so large in southern England, it is nevertheless of the same order and must indicate some fundamental change in the depositional pattern in both areas. As this population change is of considerable importance it will be discussed in detail.

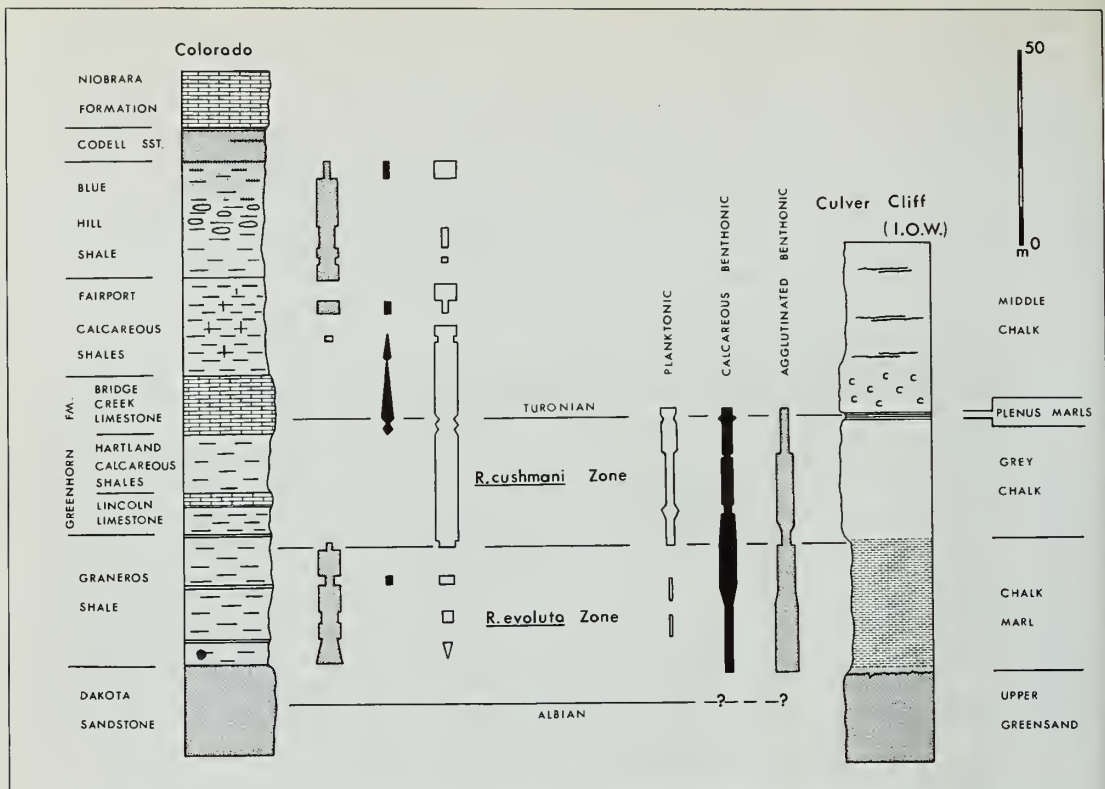


Fig. 11 Microfaunal comparison of the successions in Colorado and the Isle of Wight (England).

Grimsdale & van Morkhoven (1955) attempted to formulate a method facilitating accurate estimation of the depth of deposition from analysis of faunal contents of samples. It had long been appreciated that a thanatocoenosis in an abyssal sediment from above the compensation depth would contain 90–100% planktonic foraminifera, while one from the neritic zone would be almost totally composed of benthonic individuals. However, no practical means of integrating this information into a method for determining the depth of deposition has been developed. Grimsdale & van Morkhoven's attempts used the faunal counts of samples collected on twelve traverses (largely neritic) made by Phleger & Parker (1951). Grimsdale & van Morkhoven discussed the lack of correspondence of their graphs and, after compiling a list of the limitations, concluded that while the theory was basically sound the depth of deposition could not be accurately estimated using this technique. More recently Eicher (1969a) has used population percentages to demonstrate, in a general way, the deepening and subsequent shallowing of the Greenhorn Sea in Colorado.

Flexer & Starinsky (1970), however, based the bulk of their work on the assumption of a direct relationship between the planktonic-benthonic ratio and the depth of deposition. This was following Eicher (1969a), and many other workers had concluded that determinations based only on planktonic/benthonic ratios may give incorrect results owing to the variation of such parameters as salinity, light penetration, availability of nutrients and, perhaps more significantly, temperature. We favour Eicher's broad approach and conclude that in the mid-Cenomanian of southern England, as in the United States, there was a *general* deepening of the seaway.

The planktonic/benthonic ratio plot for the Shakespeare Cliff (Dover) borehole (Fig. 12a), based on the 60/30 grain size fraction, shows the variations recorded from the Cenomanian succession at this locality. This graph shows the marked microfaunal change in the mid-Cenomanian

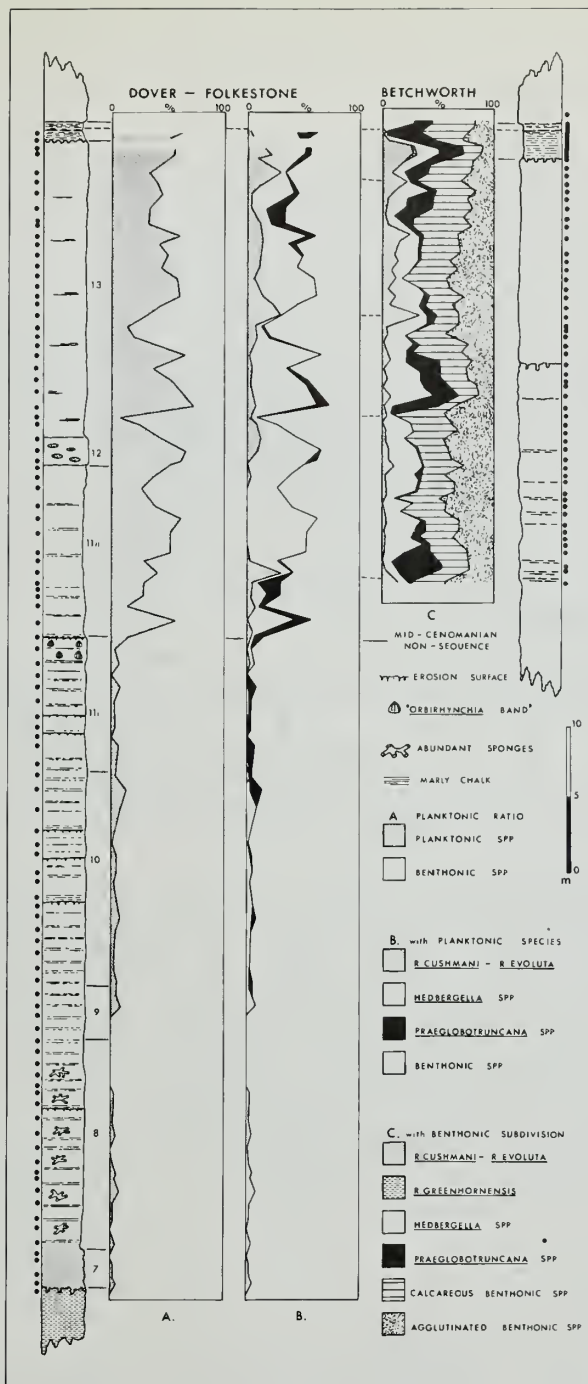
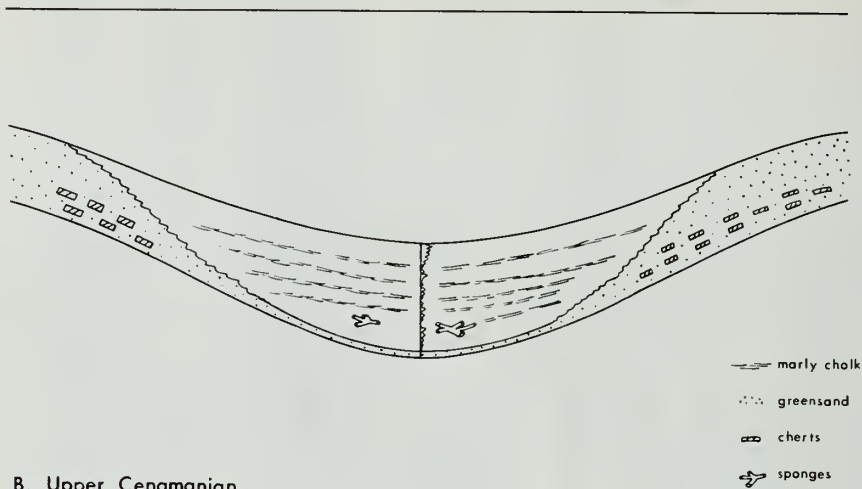


Fig. 12 Planktonic/benthonic ratio graphs, based on counts of the 60/30 grain-size fraction.
a. Outline planktonic/benthonic ratio graph for the Dover borehole.
b. Modified graph, with generic subdivision within the planktonic unit.
c. Complete analysis of the Betchworth section, with some tentative correlations with the Dover succession. (Black dots indicate sample positions.)

A. Lower Cenomanian



B. Upper Cenomanian

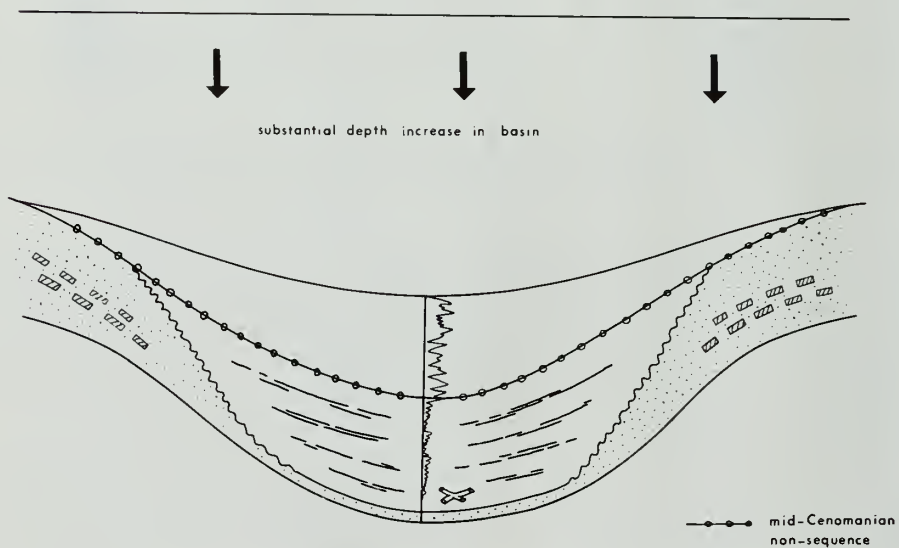


Fig. 13 Model showing the development of the planktonic/benthonic ratio graph in the Lower Chalk of south-east England.

and it is suggested that it relates to the development of the Atlantic Ocean. A model (Fig. 13) for this deepening has been developed for the Cenomanian in southern England and this will be used in the following stratigraphic analysis. The principle is that of Grimsdale & van Morkhoven (1955), although we would never attempt to attach accurate depth values to the various values of the planktonic populations.

A single major depth change does not, however, account for the planktonic/benthonic variations recorded above and below the mid-Cenomanian. Explanation of these fluctuations in terms of depth variations would require eustatic oscillations throughout the whole of the Cenomanian. While there are many distinctive sedimentological changes within the Cenomanian chalk there are none related to depth changes consistently corresponding to the planktonic/benthonic ratio changes.

Further investigation of the planktonic distribution throughout the same section shows even more significant variations. The most important single feature arising from the modified graph (Fig. 12b) is the distribution of the *Rotalipora* group, in particular *R. cushmani*. This species appears in large numbers at the mid-Cenomanian non-sequence and above this level is seen to dominate the planktonic fauna of certain horizons. These intervals of relative abundance were short-lived, although they can be traced laterally over much of southern England. One of the most striking comparisons is between the section at Dover and that recorded by Diver (1968) from the Betchworth Limeworks, Surrey (Fig. 12c). These two graphs can be correlated easily, even though the two localities are nearly 100 km apart. The close correspondence of the faunal populations at particular stratigraphic levels must be due to a similarity in the conditions of deposition, and in attempting to elucidate the reasons behind this pattern the following points are relevant.

1. While one can relate the faunal change in the mid-Cenomanian to an increase in the depth of the Cenomanian sea, it seems unlikely that all the changes above and below this level can be attributed to the same cause.
2. The features producing the faunal changes – in particular the levels of abundant *Rotalipora* – appear to be of relatively short duration.
3. Individual features of the graphs can be traced laterally over considerable distances, and therefore a mechanism that can affect hundreds of square miles of sea floor has to be considered.

If water depth was the major controlling influence the total number of planktonic individuals would be expected to diminish towards the margin of the basin. This is not always the case and in west Dorset and south Devon values of nearly 40% have been recorded for the planktonic component of the fauna. This indicates some other distribution control, allowing the planktonic individuals access to these more marginal environments. The levels of abundant *Rotalipora* are therefore thought to be indicative of warmer water conditions, and the oscillations shown in Fig. 11c indicative of the passage of warm water currents over the whole of southern England. Periodically shifting water masses, alternately warmer and cooler, could provide the large areal coverage required to explain the lateral consistency of the graphs. While the depth changes could still occur, this explanation obviates the need for marked eustatic changes at frequent intervals. Their effects, over an area as small as southern England, would be essentially synchronous.

It is suggested that a detailed study of the planktonic/benthonic ratios for the Cenomanian, as well as other stages in the Upper Cretaceous, could shed much light on the problem of chalk deposition. However, the study of chalk deposition, phytoplankton production and their relationship to palaeocurrents is beyond the scope of this paper (Hart & Carter 1975).

The oscillations in the value of the planktonic-benthonic ratios, while occurring in the Lower Cenomanian on a very limited scale, are more prominent above the mid-Cenomanian non-sequence. The level at which this change occurs deserves detailed attention. It displays one of the most striking faunal changes recorded in the whole of the mid-Cretaceous, and its field relationships must be described. It is a non-sequence that can be located at many places in southern England. The most characteristic exposure is that between Folkestone and Dover, at the foot of Acker's Steps. Under the edge of the concrete sea defences the characteristic limestone/marl cycles of the Chalk Marl are visible on the foreshore. These become less marly upwards, and terminate

abruptly at a burrowed surface marking a hiatus in deposition. Darker sediment from above fills the burrows and small fragments of material from below are sometimes found resting on the burrowed surface. Four of these cycles contain abundant *Orbirhynchia mantelliana* (J. Sowerby) in a fauna that places these beds in the *Turrilites costatus* Assemblage Zone of Kennedy (1969). At the top of a particularly strong cycle the brachiopod fauna disappears and it is at this level that the microfaunal change occurs. While it is possible to demonstrate an angular discordance between foraminiferal zones at this level on plotted cross-sections, in the field in south-east England it is recognizable only as the top of a particularly well-developed cycle. In Cambridgeshire, Bedfordshire and Buckinghamshire, however, this part of the succession is marked by the appearance of a series of hard limestone beds, each usually underlain by a thin band of slightly rounded pale brown phosphates. This series of limestones is known either as the Totternhoe Stone, the Burwell Rock or the Chilton Stone, depending on the locality. While the phosphate horizon indicates the level of the most important environmental change, it does not mark the non-sequence, which is found a few centimetres further up. However, the non-sequence still corresponds with the top of the *Orbirhynchia mantelliana* band. Jeans (1968) recognized the importance of this brachiopod 'pulse fauna' and related this particular level to those of other 'pulse faunas' found throughout the Lower Chalk. The presence of the phosphate bed below the brachiopod level indicates a period of shallowing prior to the deepening effect of the non-sequence. This shallowing has also been demonstrated by Burnaby (1962) using the benthonic foraminifera of the Chalk Marl succession at Barrington (Cambridgeshire). Although the effect is less well marked in south-east England, a similar temporary decrease in water depth is reflected by the reappearance of rare specimens of *Lingulogavelinella jarzevae* and the occasional occurrence of specimens of

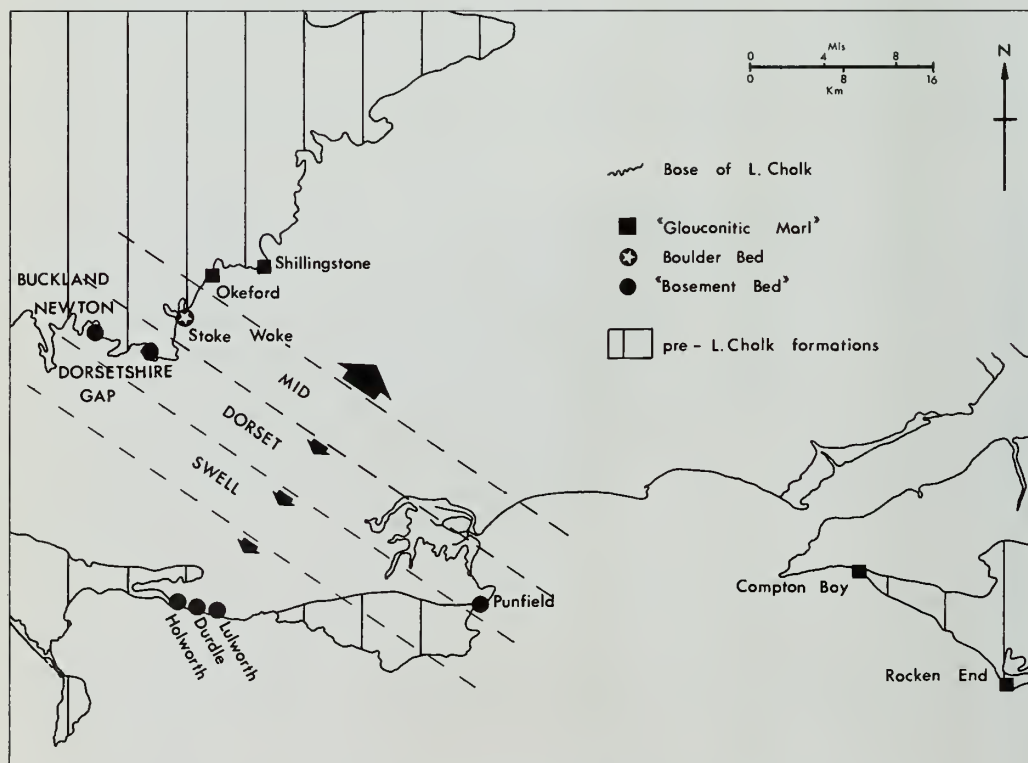


Fig. 14 The variation in the form of the 'Basement Bed' of the Lower Chalk in Hampshire and Dorset.

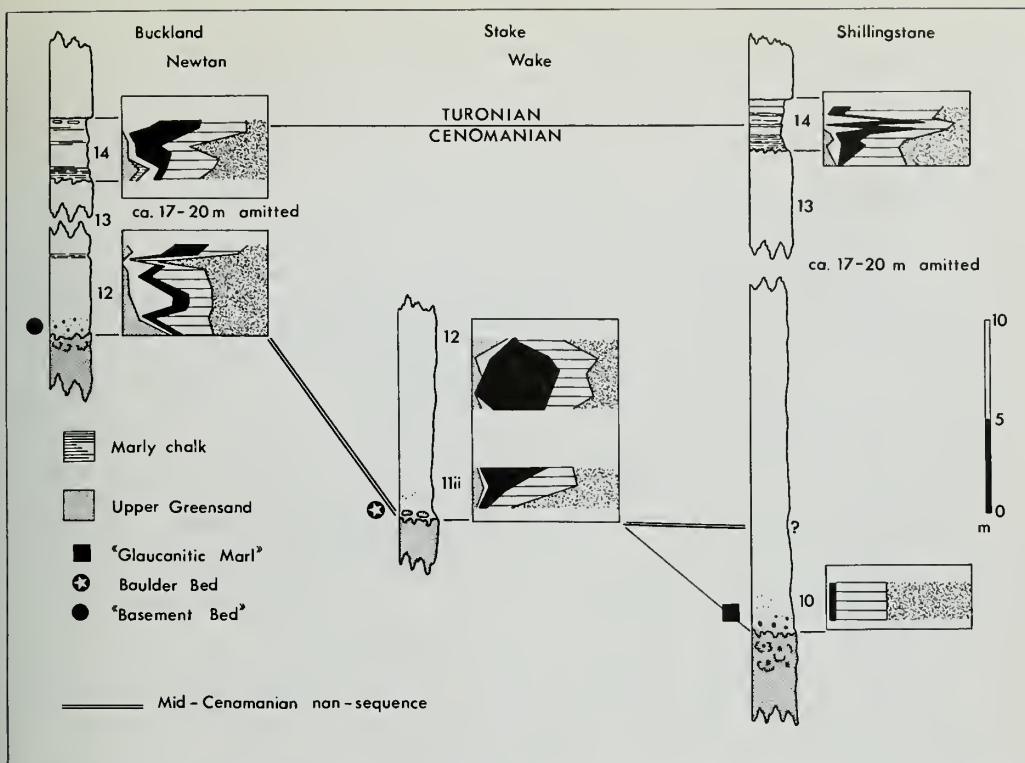


Fig. 15 The relationship between the mid-Cenomanian non-sequence and the Chalk Basement Bed in central Dorset. The ornament used in the planktonic/benthonic ratio graphs is explained in Fig. 12c.

Marssonella oxycona (Reuss) mimicking *M. ozawai* in the two cycles immediately preceding the non-sequence.

Returning to the model (Fig. 13), chalk deposition should continue above the non-sequence in the centre of the basin and, since the lithological changes would be slight, it could only be detected palaeontologically. However, on the margins of the basin a more dramatic sedimentological change would be expected. In these areas the calcareous sandstones (postulated in the model) would be replaced by Middle and Upper Cenomanian chalk, giving an easily recognizable horizon. It is not surprising that in Dorset the non-sequence becomes a feature of such importance that it dominates the whole of mid-Cretaceous stratigraphy in that area. The data concerning this level has been summarized by Kennedy (1970: fig. 19) although no real explanation of the feature was given in his account. In Dorset (Fig. 14) there is a transition from an 'invisible' non-sequence into the prominent Chalk Basement Bed – with its rich fauna of phosphatized macrofossils. To the east of Stoke Wake (ST 763067) the Lower Chalk succession (Fig. 15) is normal, with a bed of 'glaucanitic marl' at its base. This marl – as was explained by Carter & Hart in the discussion of Kennedy (1969) – is not the same age as the 'Glaucanitic Marl' of the Folkestone section. The most suitable sequence for direct comparison is that at Shillingstone Lime Works (ST 824098) (Fig. 22, p. 77), where 42 m of chalk below the Plenius Marls has been recorded. A short distance to the south-east of the quarry the base of the chalk can be seen in the banks (ST 846106) of the River Stour (Kennedy 1970: 622). The base of the chalk at this locality is completely different from that at Stoke Wake (Fig. 15) where a layer of large, glauconite-stained limestone cobbles marks the highly irregular contact. At Dorsetshire Gap (ST 742033) and Buckland Newton (ST 703051) the base of the chalk shows the Chalk Basement Bed. The graphs in Fig. 15 demonstrate

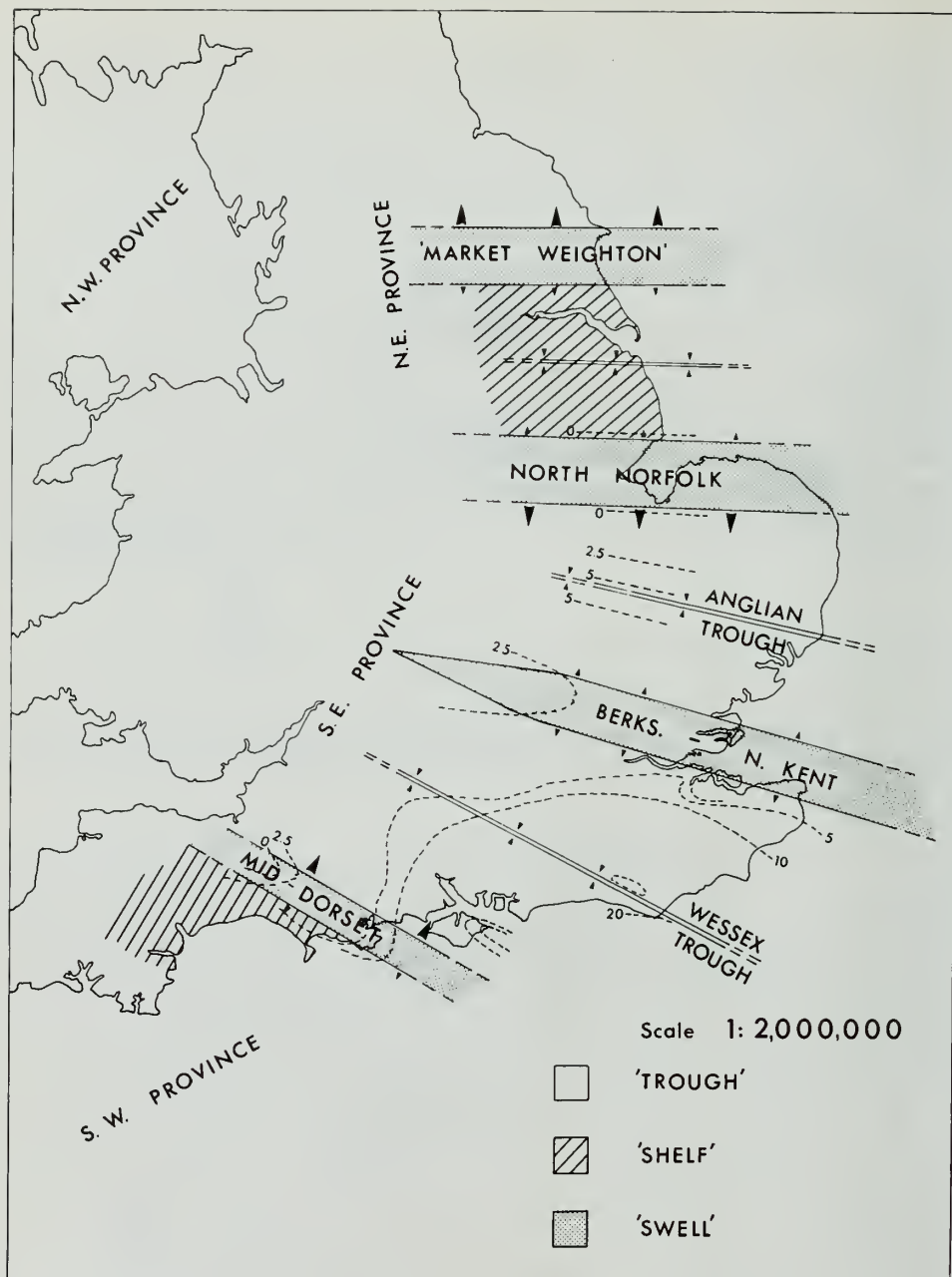


Fig. 16 Location of the major 'axes' affecting Lower Chalk sedimentation in England, and their relationship to the thickness of the *Actinocamax plenus* Marls. Isopachytes (in feet) based on the work of Jefferies (1963) and the present authors. These axes are also used in the delimitation of the provinces discussed in the stratigraphic account.

that west of Stoke Wake the mid-Cenomanian non-sequence is coincident with the base of the Chalk, while to the east of this locality the base of the chalk is below this level. The Chalk Basement Bed is therefore shown to be the visible expression of the mid-Cenomanian non-sequence. This phosphate conglomerate can be traced over the greater part of Dorset, as well as parts of Somerset and Devon, wherever the base of the chalk is exposed. The position of this feature in Devon is slightly complicated by the appearance of the Cenomanian Limestones, to be discussed in a later section. By plotting the base of the chalk (i.e. Basement Bed, nodule bed and glauconitic marl) it is possible to determine the areal relationship of these features. This is shown in Fig. 14. The appearance of the Basement Bed coincides with the already-described line of the Mid-Dorset Swell (Drummond 1970; Kennedy 1970), which indicates this feature persisted into the mid-Cenomanian, and even at this late stage was actively controlling sedimentation in the area. Jefferies (1963) has also attempted to show, somewhat indirectly, that the sedimentation of the Plenus Marls was also controlled by the same, or similar, basement structures. Jefferies' data, and the results of our own field work, are presented in Fig. 16 which shows how the isopachytes of the Plenus Marls reflect the presence of these 'basement structures'. The section between Dover, Eastbourne and the Isle of Wight (Fig. 19, p. 74) demonstrates the relationship between Plenus Marls sedimentation and the mid-Cenomanian non-sequence. It is interesting to note that the Plenus Marls succession is essentially uniform above the erosion surface at the base of Bed 4, the overall variations in thickness being largely due to variations in Beds 1–3. The main controlling influence on the sedimentation pattern is therefore Cenomanian and not Turonian as suggested by Jefferies (1963). The uniform nature of the succession above the Bed 3/Bed 4 boundary also adds weight to the suggestion that this level is the most suitable for the Cenomanian/Turonian boundary. The isopachyte map (Fig. 16) also can be used to delimit depositional trends which we will subsequently show are the most important features of the Cenomanian palaeogeography of the Anglo-Paris Basin. The map also can be used to delimit the following four provinces to be used in the stratigraphic analysis.

SE Province – characterized by the standard succession of the Gault Clay, Upper Greensand and Lower Chalk of normal depositional type.

SW Province – characterized by thick sequences of Upper Greensand, the absence of the true Gault Clay, the appearance of thin sandy limestones which are overlain by atypical chalk, which usually displays a marked phosphatic conglomerate at its base (the 'Chalk Basement Bed' of Kennedy (1970) and Drummond (1970)).

NE Province – characterized by a reduced Lower Chalk succession, red and pink chalks, nodular chalks and the 'Black Band' (Plenus Marls).

NW Province (including Antrim, the Inner Hebrides and Argyll) – characterized by thin glauconitic sands, overlain by pure glass sands and very thin, hard limestones (commonly recrystallized).

Stratigraphic analysis

Although much new information concerning the mid-Cretaceous of the British Isles is available no attempts at a comprehensive survey have been made. Specific topics have received detailed attention, but only Kennedy (1969, 1970) has provided a general account of the Lower Chalk over the whole of southern England. While his two papers give a detailed account of the sections visible in the field, he has made no attempt to synthesize his data. Kennedy's correlation diagrams (e.g. 1969: fig. 16) do not fulfil our present requirements. In the example quoted above, some sections (e.g. Beddingham) are plotted at the opposite end of the diagram to those sections that are closest to them geographically. However, Kennedy's data on most of the sections used in this account is adequate and obviates the need for lengthy repetition.

The SE Province is discussed below as an introduction to the more detailed account of the south-west of England. The NE and NW Provinces have not been studied in the same detail and only short outline reports of those areas are given.

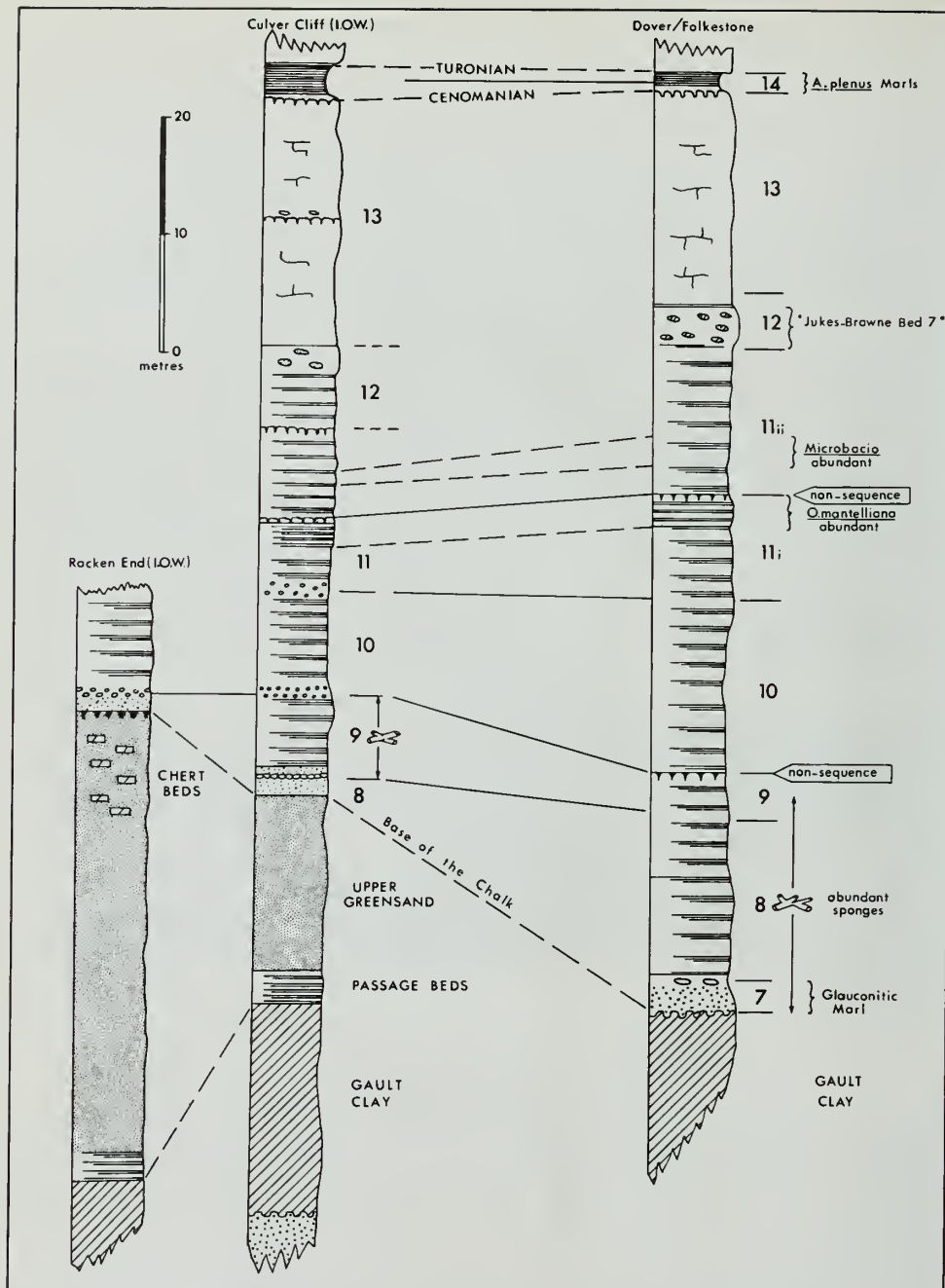


Fig. 17 The more important lithological features of the SE Province, together with the correlation of successions in Kent and the Isle of Wight.

a. South-east Province

This province consists of a single basin of deposition which continues across the English Channel into the Paris Basin. It is bordered by two distinct features, the Mid-Dorset Swell to the south-west and the North Norfolk Swell to the north. The central feature of the Berkshire – North Kent Swell, barely noticeable in central England, becomes more prominent in northern France.

As the more important lithological features of this area are already well known, Fig. 17 shows only three sections. Those shown illustrate the most important features encountered between Folkestone and the Isle of Wight.

i. The Plenus Marls succession remains constant in form and the individual beds and erosion surfaces (Jefferies 1962, 1963) are easily recognized.

ii. The mid-Cenomanian non-sequence cuts across the Lower Chalk succession, immediately above the *Orbirhynchia mantelliana* band.

iii. The relatively minor non-sequence at the Zone 9/Zone 10 boundary at Folkestone is marked in the Isle of Wight by a phosphate bed.

iv. The age of the base of the Lower Chalk varies between Dover and the Isle of Wight. At Culver Cliff the lowest beds correspond to a horizon well above the base of the Dover succession.

v. The Gault Clay passes westwards into the Upper Greensand succession.

vi. The Chert Beds appear only in the upper levels of the Upper Greensand, and in the SE Province are restricted to the southernmost tip of the Isle of Wight and the area around Warminster (Wiltshire).

The SE Province can best be described with reference to two cross-sections. The more important (Fig. 18) traverses southern England from Hunstanton in the north to Buckland Newton in the south. The more southerly profile from Folkestone/Dover to Swanage (Fig. 19, p. 74) relies on coastal exposures, although some borehole evidence has been incorporated. Although both sections are oblique to the main structural trends, the latter can nevertheless be determined. As already noted, the Berkshire – North Kent Swell is barely noticeable in Berkshire, and only becomes important across the Channel in France. However, it can be recognized by the change in lithology across it. The main sedimentological variations in the two subsidiary troughs and the intervening and marginal swells can be summarized as follows.

i. Anglian Trough

a. The Upper Greensand is very restricted, and found only in the south-west corner.

b. The Cambridge Greensand is seen at the base of the Lower Chalk in the centre of the trough.

c. Immediately below the mid-Cenomanian non-sequence there is a series of hard limestone beds, which suggest some degree of condensation.

ii. Wessex Trough

a. The Upper Greensand is well developed over the greater part of the area.

b. The Warminster Greensand occurs below the Lower Chalk in the centre of the trough.

c. The beds below the mid-Cenomanian non-sequence contain abundant *O. mantelliana*, but are of normal lithology.

iii. The intervening and marginal swells

On the northern margin of the Anglian Trough the Gault Clay and Lower Chalk successions are condensed and thin; on the southern margin of the Wessex Trough they have been much reduced by non-deposition or erosion. Over the Berkshire – North Kent Swell between the troughs the sequence is slightly reduced by losses immediately below the mid-Cenomanian non-sequence.

While the important breaks in the succession (sub-plenus surface, mid-Cenomanian, Zone 9/Zone 10, and the Albian/Cenomanian non-sequences) can be recognized in both troughs there are slight differences in their effects. In the Anglian Trough, and particularly in the vicinity of the North Norfolk Swell, the succession appears to be reduced in thickness more by condensation of

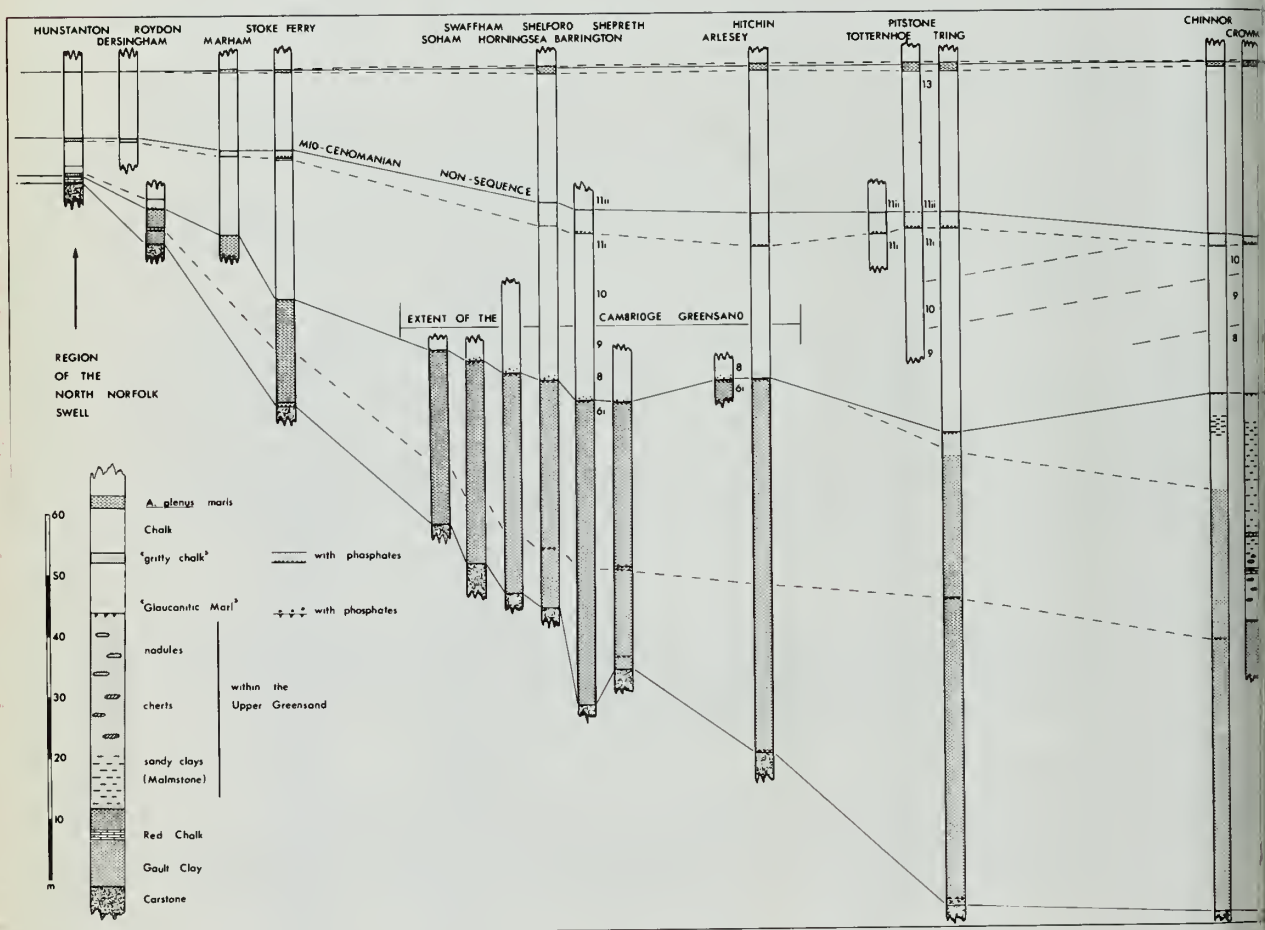
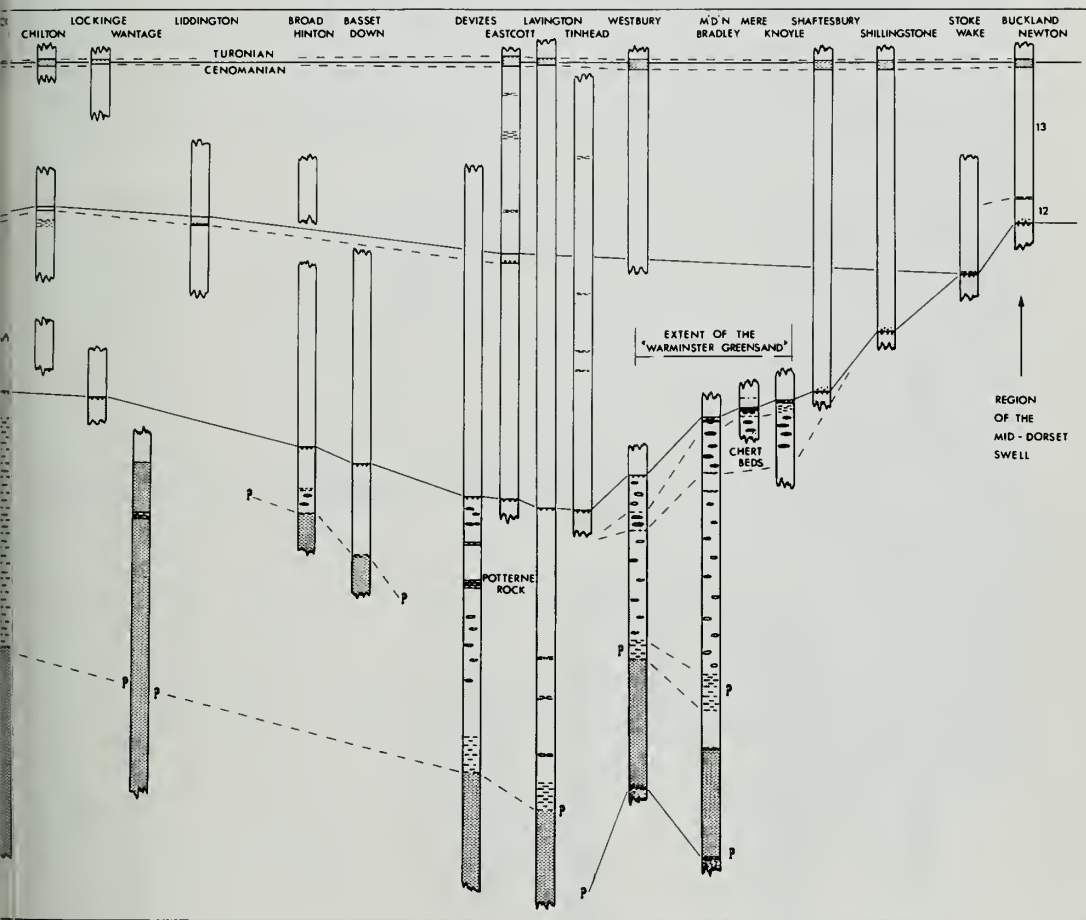


Fig. 18 The correlation of the mid-Cretaceous from



ustanton (Norfolk) to Buckland Newton (Dorset).

the individual beds than by the removal or non-deposition of parts of the succession. The Wessex Trough, on the other hand, shows normal deposition over the whole area, with marked reductions of overall thickness caused by erosion or non-deposition, or both. This is demonstrated when the style of deposition on the two boundary swells is compared. These differences persist beyond the confines of the SE Province; the whole of the NE Province is dominated by condensed successions, while the SW Province successions show prominent erosion surfaces.

The stratigraphy of the SE Province will now be considered by regions.

1. The margin of the North Norfolk Swell

It is unfortunate that micropalaeontological control is so poor in the area bordering the North Norfolk Swell. This is due to a combination of poor exposure, difficult lithology and as yet incomplete sampling of that area. At present only an indication of the trends in this area can be given. Hunstanton is on the edge of a shelf, south of which all parts of the succession expand rapidly in thickness. This is particularly true of the Gault Clay, although the thickening of the Lower Chalk is also striking. However, both units are incomplete, even in the centre of the Anglian Trough.

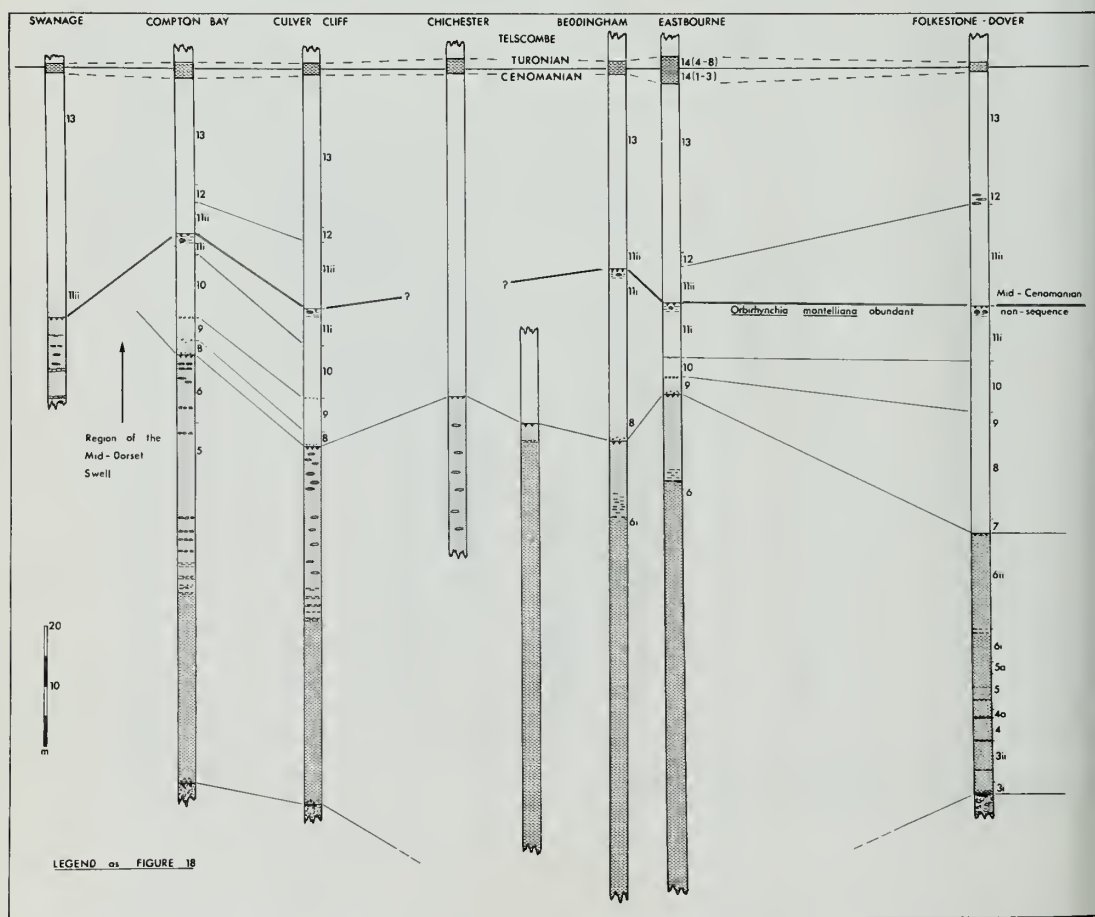


Fig. 19 The correlation of the mid-Cretaceous from Dover (Kent) to Swanage (Dorset). (The Eastbourne succession has provided several workers (e.g. Kennedy 1969) with a problem, and the thickness used in this account is one of many recent estimates. Faulting has completely broken up the lower levels of the sequence.)

2. The Anglian Trough

In this area the base of the Lower Chalk is represented by the Cambridge Greensand (Hart 1973a). Detailed microfaunal analysis has shown that the age of the Cambridge Greensand is upper Zone 8 (uppermost *Hypoturrillites carcitensis* Assemblage Zone of Kennedy 1969), even though the only dateable macrofaunal elements are from the *dispar* Zone. The underlying Gault Clay belongs, on microfaunal grounds, to the *Arrhaphoceras substuderi* Subzone of the *dispar* Zone. This shows that the upper part of the *dispar* Zone is not represented in this part of Cambridgeshire, even

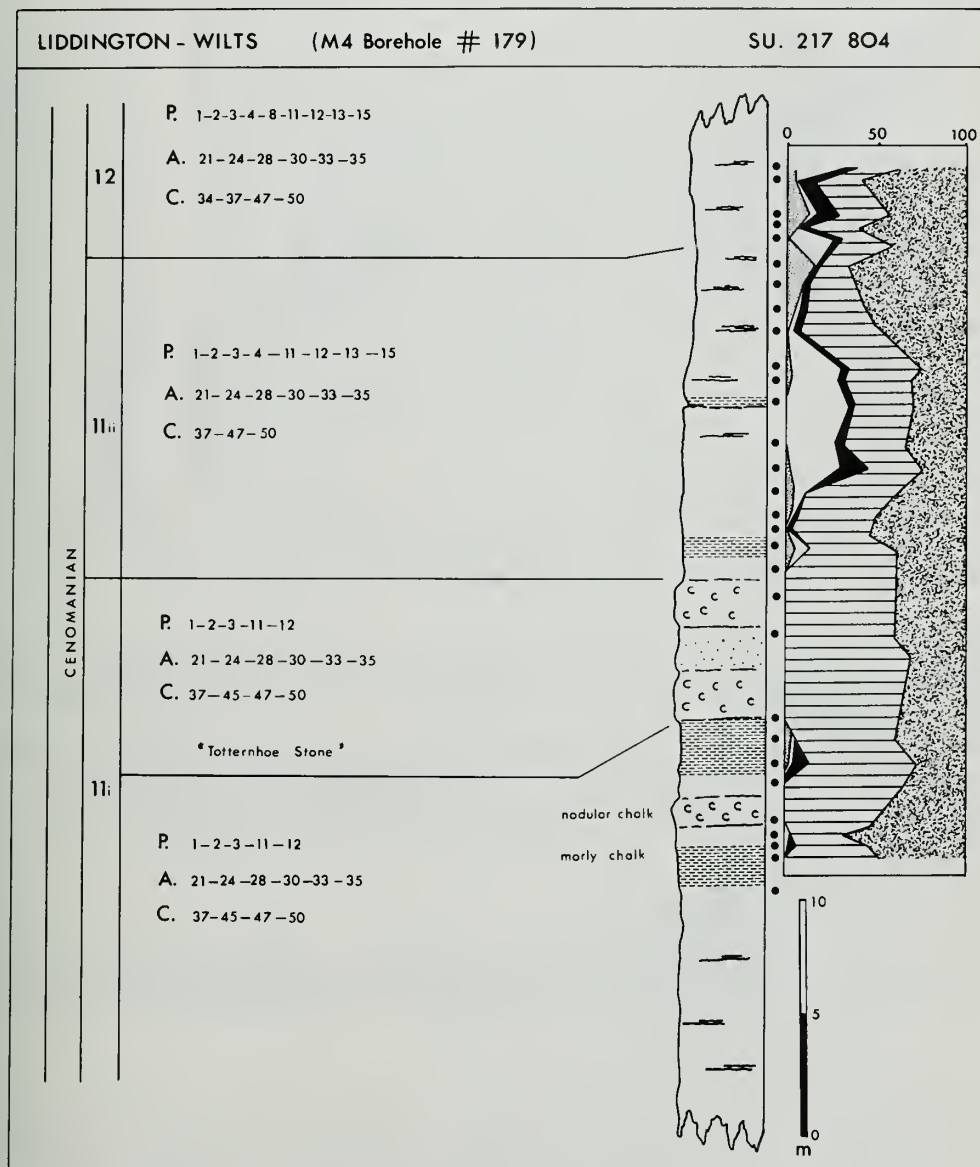


Fig. 20 Microfaunal details, Liddington Borehole, Wiltshire. The ornament used in the planktonic/benthonic ratio graph is explained on Fig. 12c. The species lists are in three categories (P. - planktonic, A. - agglutinated benthonic and C. - calcareous benthonic), the numbers referring to the species listed on the range chart (Fig. 9). The black dots indicate sample positions in all vertical sections.

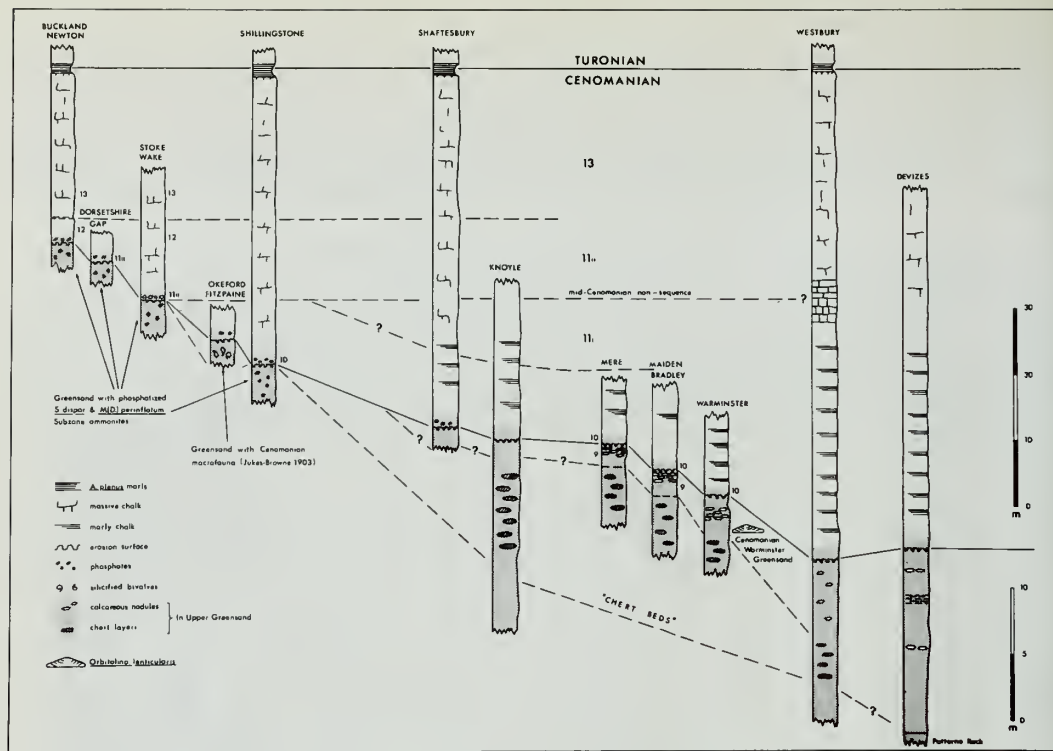


Fig. 21 The correlation of the mid-Cretaceous from Devizes (Wiltshire) to Buckland Newton (Dorset).

though its fauna can be collected from the famous 'coprolite bed'. The relationship between an absent *dispar* Zone and an overlying bed containing *dispar* faunal elements is discussed in the section on the SW Province.

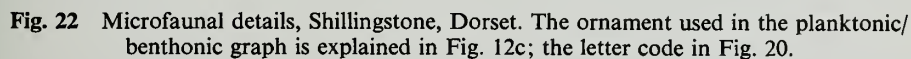
The other characteristic feature of the Anglian Trough is the presence of the Totternhoe Stone (Chilton Stone, Burwell Rock) immediately below the mid-Cenomanian non-sequence. The relationship between this lithological unit and the non-sequence has already been described (p. 66). The distribution of this bed is shown in Fig. 18, and the succession above it in the Liddington borehole in Fig. 20.

3. The Berkshire – North Kent Swell

At present little is known about the sequences in this area. Work in progress indicates a large hiatus below the mid-Cenomanian non-sequence in west central Buckinghamshire, but the Albian–Cenomanian boundary has not yet been studied.

4. The Wessex Trough (North-western Region)

At present very little information is available concerning the base of the Lower Chalk and the fauna of the Upper Greensand from the area between Chinnor and Warminster. This region has not been studied in the same detail as south Wiltshire and north Dorset. However, Kelly (1971) recorded Albian ammonites from the Upper Greensand at Edington (Wiltshire). Spath (1923–43) demonstrated that the Potterne Rock contained a rich, non-phosphatized ammonite fauna of *Callihoplites auritus* Subzone age, while above this horizon the 30 m of glauconitic sands yielded elements from the *Stoliczkaia dispar* Zone. At Edington, Kelly records a phosphatized fauna of



the *auritus* Subzone, while the rarer, non-phosphatized elements of the fauna indicate a slightly younger horizon. No microfaunal information is available from here.

5. The margin of the Mid-Dorset Swell

Since important changes occur adjacent to the Mid-Dorset Swell the area between Warminster and Buckland Newton has been studied in considerable detail. In this region (Fig. 21) the Lower Chalk thins from approximately 60 m in the Westbury area to about 25–30 m in mid-Dorset. Unfortunately, the all-important mid-Cenomanian non-sequence is not exposed and the lithological sequences must be constructed without reference to one of the more important datum levels within the Lower Chalk. As the thickness of the Lower Chalk is known at several localities some information can be gleaned from the age determinations of the lowest levels. At all the localities studied (Stour Bank (ST 846106, Fig. 22), Mere (ST 804323, Fig. 23) and Maiden Bradley (ST 797390, Fig. 24)) the basal, glauconitic chalk yields a Zone 10 microfauna, although the precise position within that zone cannot be determined. The sequence below this zone is highly complex, and contains a series of boulder or ‘popple’ beds, greensands, and greensands with

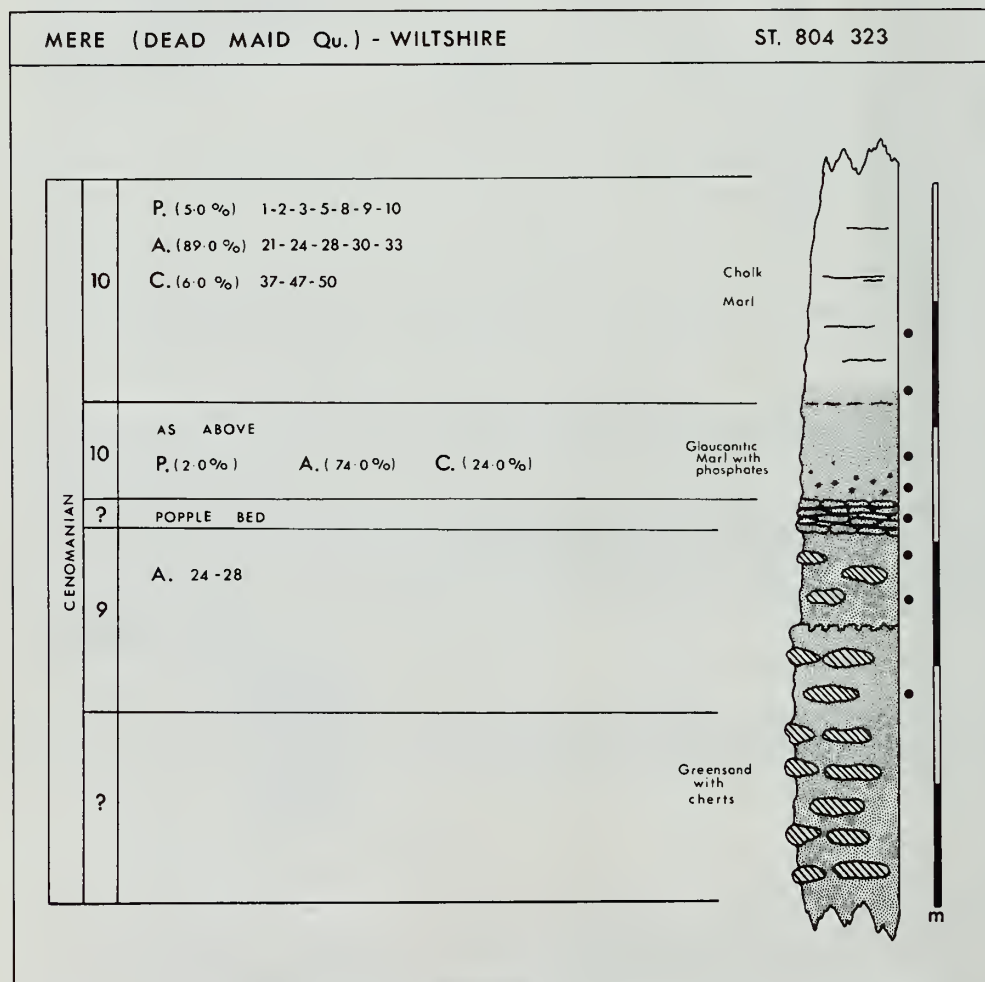


Fig. 23 Microfaunal details, Dead Maid Quarry, Mere, Wiltshire. See Fig. 20 for explanation of letter code.

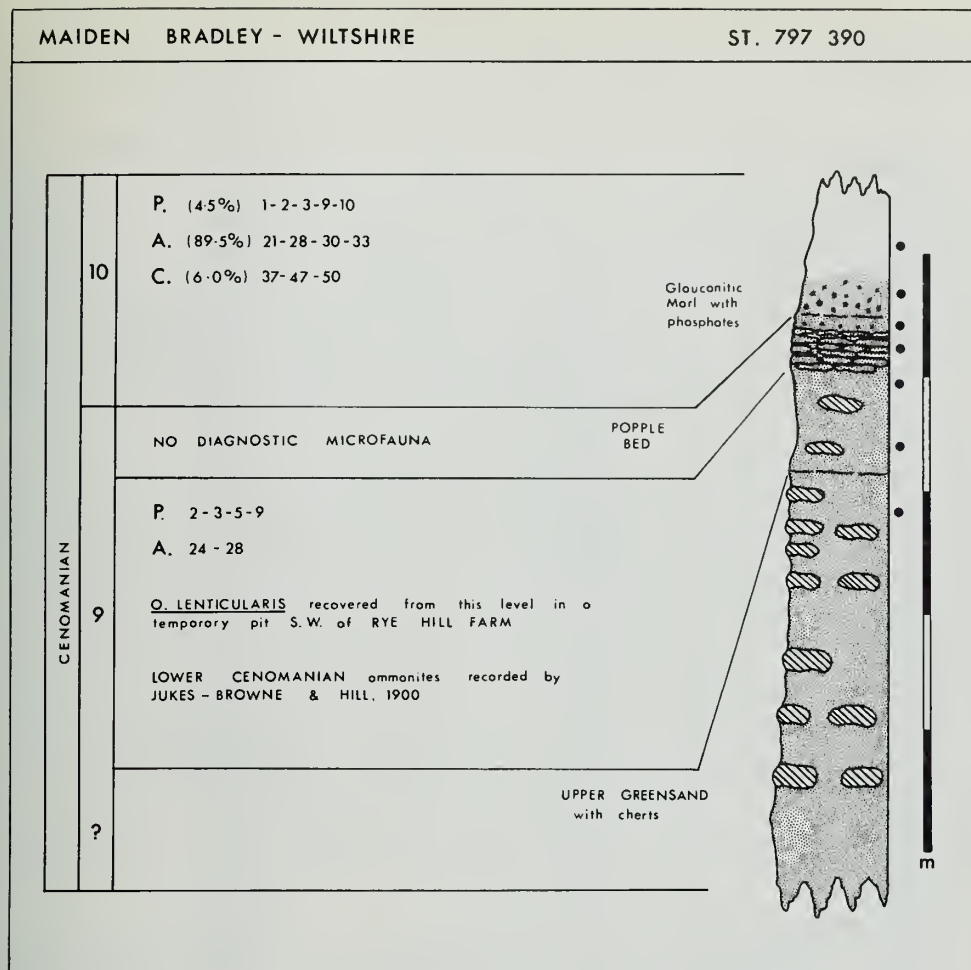


Fig. 24 Microfaunal details, Maiden Bradley, Wiltshire. See Fig. 20 for explanation of letter code.

cherts. The most important lithological unit is the Warminster Greensand, with its well-known Lower Cenomanian fauna (Jukes-Brown & Hill 1900: 238). This greensand, and its lateral equivalent the Rye Hill Sand, is extremely poor in microfossils although Dr P. V. O. Drummond has presented us with a magnificent specimen of *Orbitolina lenticularis* (Blumenbach) washed from a temporary exposure in the greensand. In this area the underlying chert-bearing greensand has yielded no diagnostic macrofossils (Jukes-Browne & Scanes 1901, Edmunds 1938, Kennedy 1970). The age of the base of the Chalk (Zone 10) given by the microfauna appears to conflict with the ammonite dating of Kennedy (1970: 620), who records a Lower Cenomanian fauna, probably earlier than the main *saxbii* assemblage fauna of south-east England. While Cenomanian sands are also present below the base of the Chalk at Knoyle Corner (ST 897307) and Melbury Down (ST 875207) (Jukes-Brown & Hill 1900: 160-161; 1903: 104-105; Mottram, Hancock & House 1956), there must be a distinct change before the River Stour is reached at Stour Bank (ST 846106). At this locality the uppermost Upper Greensand is a complex bed of glauconitized cobbles set in softer greensand. There is an abundant macrofauna of silicified and phosphatized bivalves and ammonites. The 'glauconitic marls' which overlie this bed contain a very rich phosphatized fauna (Kennedy 1970: 623) and an unphosphatized one belonging to the *carcitanensis* Assemblage

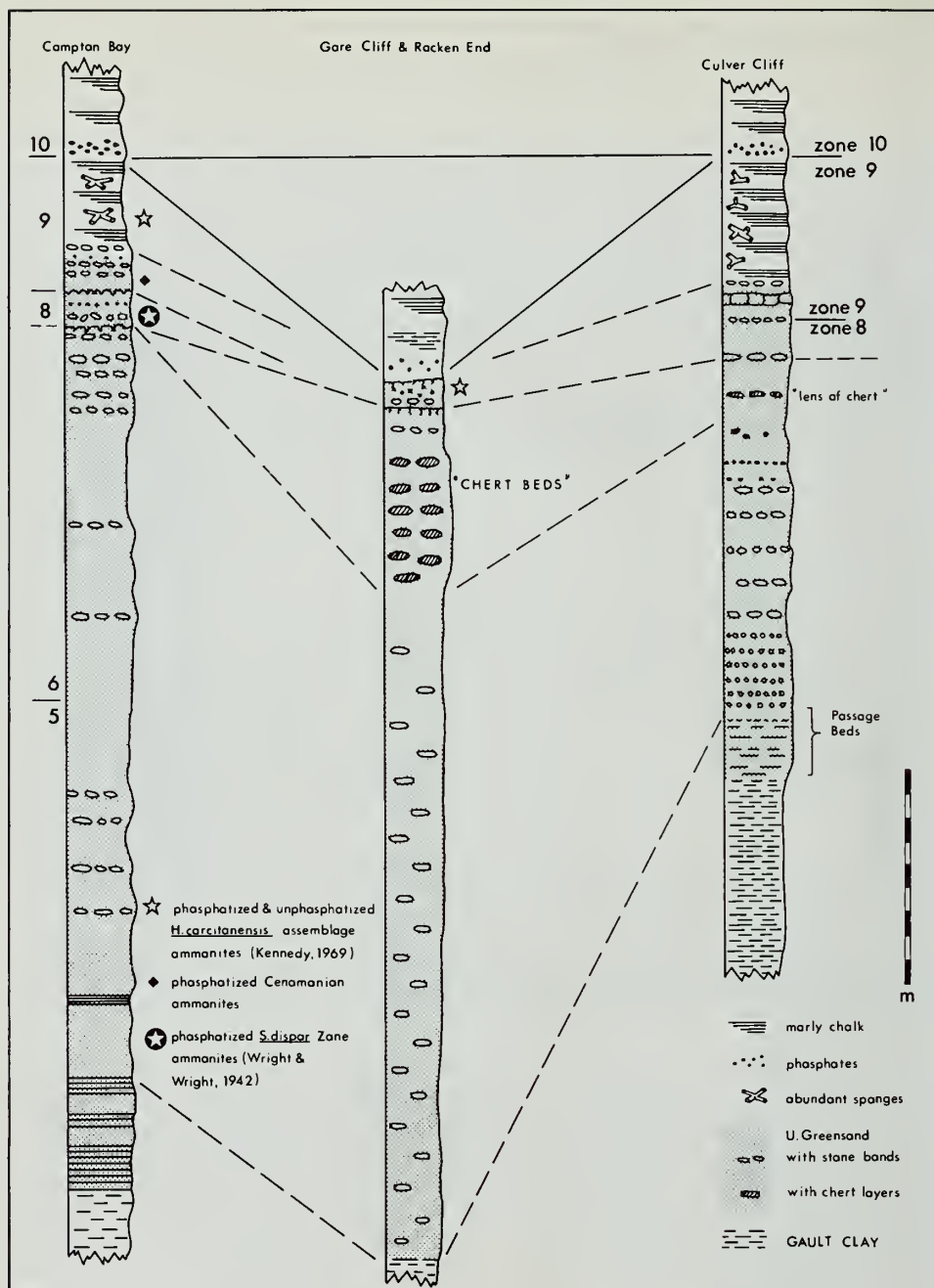


Fig. 25 A correlation of the Lower Cenomanian and Upper Albian successions of the Isle of Wight.

Subzone. This locality is interesting as it is one of the places in south-west England where a *S. dispar* Zone fauna is found within the Upper Greensand. The phosphatized fauna, with its associated silicified bivalves, can also be found at Dorsetshire Gap (ST 742033) and Buckland Newton (ST 703051). Its preservation and concentration must indicate that it is a reworked deposit. Its position is somewhat analogous to that of the phosphatized *S. dispar* Zone fauna found in the Upper Greensand below the Chert Beds on the Purbeck coast (Fig. 45, p. 103), and that of the *S. dispar* Zone fauna from the upper levels of the Upper Greensand succession in the Isle of Wight. It is important to note that the basal beds of the Chalk in the Stour Valley do not contain elements of an Albian fauna, the latter being completely within the Upper Greensand. If this faunal distribution is compared with that seen in Cambridgeshire, clearly there are some important differences. In Cambridgeshire, the phosphatized *S. dispar* Zone fauna is found within the Chalk succession, above the major non-sequence of that area. As the lowermost Chalk at Stour Bank occupies a position above the Zone 9/Zone 10 non-sequence, there is a considerable gap in the succession between the basal Chalk and the underlying (?) uppermost Albian Upper Greensand. It follows also that the Chert Beds (see Fig. 21) are of post-*S. dispar* Zone age.

The Isle of Wight is in a similar position relative to the Mid-Dorset Swell as are south Wiltshire and north Dorset. The general section across it (see Fig. 19) requires some amplification. Unfortunately both the microfaunal and macrofaunal dating is inconclusive. A summary of the available data from both fields is shown on three sections in Fig. 25. The most important feature is the phosphate bed, which coincides with the Zone 9/Zone 10 boundary. This marks a non-sequence, which can be shown to be diachronous from south to north over the island and equates with that forming the base of the Chalk in the Warminster area. A few metres below the phosphate conglomerate at Compton Bay, in the uppermost Upper Greensand, occurs the phosphatized Upper Albian (*S. dispar* Zone) fauna described by Wright & Wright (1942), in a similar position to that recorded from Dorsetshire Gap and Stour Bank. This fauna occurs on this side of the Mid-Dorset Swell when the Chert Beds are found in the succession. The base of the 'glauconitic marl', both at Culver Cliff and Compton Bay, is in the upper levels of Zone 8 – well up in the Lower Cenomanian, at about the same level as the base of the Chalk in the Cambridgeshire area.

If the phosphatized *S. dispar* Zone fauna, seen at Compton Bay, is from a stratigraphically lower horizon than the chert-rich sequence, then this horizon, though undated, is identical with that found in south Wiltshire.

6. The Wessex Trough (South-eastern Region)

The greater part of the Lower Chalk succession can be correlated along the south coast towards Dover with little difficulty. The only problem is the dating of the Upper Greensand and the base of the Chalk. Although no diagnostic fossils have been found in the topmost levels of the Gault Clay or the overlying Upper Greensand, at Eastbourne the highest levels of the Gault Clay are thought to fall within the *inflatum* Zone (Kennedy 1967: 368; 1969: 504). The 'glauconitic marl' contains abundant, phosphatized *carcitanensis* Assemblage Subzone faunal elements as well as an unphosphatized fauna of the same assemblage. The bed of phosphatized ammonite just above this level correlates with that on the Isle of Wight at the Zone 9/Zone 10 boundary. This agrees with a Zone 9 age for the 'glauconitic marl'. The microfauna of the Upper Greensand on the fore-shore at Beachy Head is not diagnostic and the junction with the Gault Clay is so broken up and confused that the dating of the clay as Zone 6 has little bearing on that of the greensand. However, the nearby Beddingham Limeworks (TQ 440093–440062) does provide a more complete and essentially less complicated succession. In the large pit near the railway line about 12–15 m of blue, sandy clay can be seen to become more silty and glauconitic when traced up the sequence. The transition into the Upper Greensand is very gradual and the boundary is very difficult to place. The results of our Beddingham investigations are shown in Fig. 26. The Gault Clay/Upper Greensand transition contains a Zone 6 fauna, but the recorded species indicate that it belongs to the lower levels of the zone. The presence of *Globigerinelloides bentonensis* in large numbers supports this determination – floods of this species are also found in the Gault Clay below the Cambridge Greensand, where the upper subzone of the *S. dispar* Zone is missing.

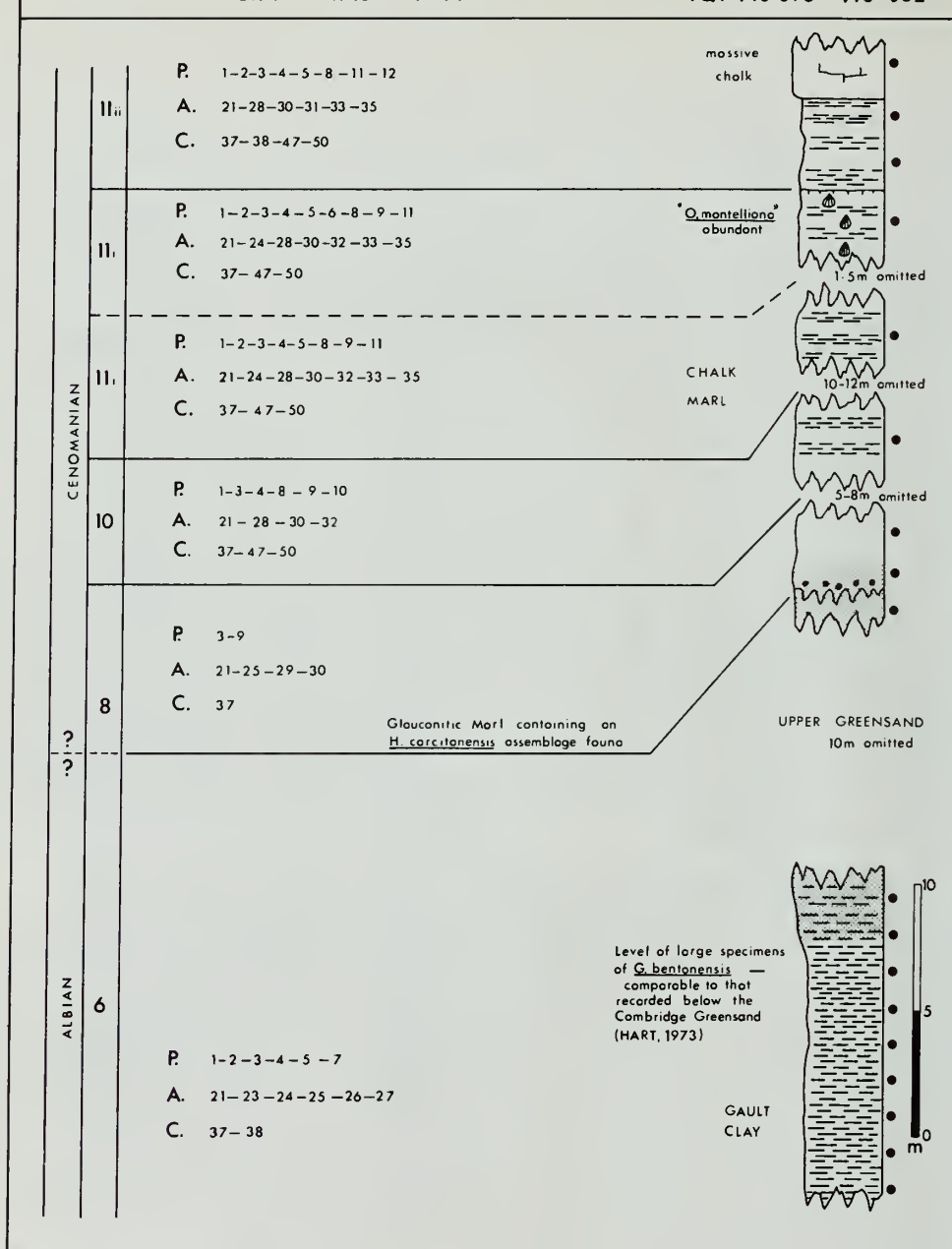


Fig. 26 Microfaunal details, Beddingham Limeworks, nr Lewes, Sussex. See Fig. 20 for explanation of letter code.

The uppermost Upper Greensand contains the same fauna, and this shows that the uppermost Albian is wanting in this area. The fauna from the base of the overlying 'glaucconitic marl' contains elements from the upper levels of Zone 8 (*Flourensina intermedia*, *Marssonella ozawai*, *Arenobulimina advena*, *Plectina mariae*, etc.) which are from slightly lower in the succession than on the coast only a few km away. The upper levels of the 'glaucconitic marl' at Beddingham (Kennedy 1969: 501) contain a sparse *carcitanensis* Assemblage fauna. As Zones 7 and 8 are thought to equate with this assemblage subzone there is no dispute between the microfauna and the macrofauna at this locality. As at Barrington (Cambridgeshire) a substantial thickness of the Lower Cenomanian is not represented, and so the situation in both the Anglian and Wessex Troughs is remarkably similar. The main difference is the absence of the derived, phosphatized *S. dispar* Zone elements from the more southerly of the two troughs.

The Folkestone succession, used as the standard for the Lower Chalk and Gault Clay, is relatively uncomplicated. The zonal chart (Fig. a, p. 53) has been based on this sequence. The Dover succession has also been used to demonstrate the use of the planktonic-benthonic ratio graphs in the Lower Chalk and its correlation with that recorded from the Betchworth Limeworks (TQ 207517) (see Fig. 12). The series of disused pits at Betchworth was studied in detail by Diver (1968), Bigg (1968) and Jaworski (1968). The succession exposed is rendered additionally useful by its proximity to the Fetcham Mill Borehole (Gray 1965). The succession in this borehole below the Plenius Marls is seen to correlate precisely with that described by Diver (1968), and the thickness of the 'glaucconitic marl' compares favourably with the values obtained by Jaworski (1968). The 'glaucconitic marl' belongs in Zone 9 while the overlying Chalk is of Zone 10 age. The Upper Greensand contains a Zone 7 or Zone 8 fauna, which places it within the Lower Cenomanian. This determination agrees with the evidence from the Fetcham Mill Borehole in which the first identifiable ammonite of Albian age, *Pleurohoplites* cf. *subvarians* Spath, does not occur until a

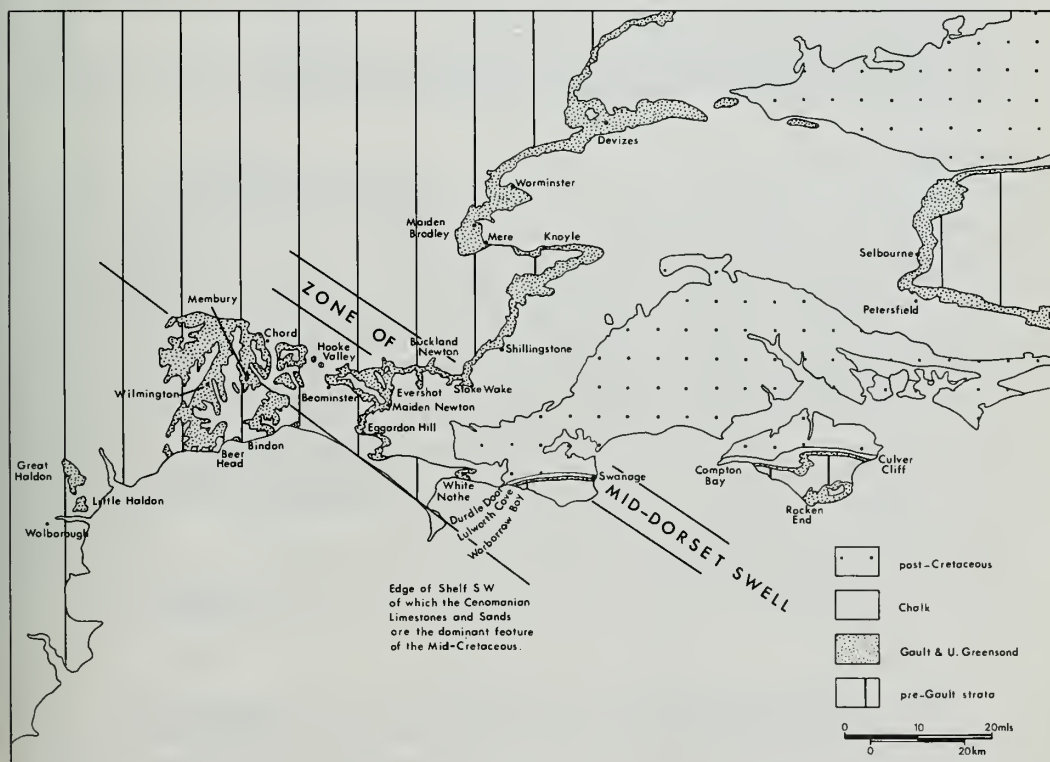


Fig. 27 The more important localities and geological features of the south-west Province.

depth of 883'1" (269.16 m) (with *Lephoplites* cf. *pseudoplanus* Spath at 883'2" (269.19 m) and *Callihoplites* cf. *tetragonus* (Seeley) at 895'2" (272.85 m)). This fauna is from the *substuderi* Subzone of the *S. dispar* Zone, and not (Casey in Gray 1965, Appendix B: 105) from the higher *perinflatum* Subzone. This ammonite evidence and the last record of *Schloenbachia* sp. at 840'11" (256.31 m), within the 'glauconitic marl', was taken into account when plotting the base of the Cenomanian. A sample from above the 'glauconitic marl' from the borehole at depth 834'–835' (c. 254.36 m) was studied by M. B. H. and shown to contain a fauna that places it close to the Zone 9/Zone 10 boundary. Another sample from 854'–855' (c. 260.45 m) contains transitional forms between *Arenobulimina chapmani* and *A. advena* and must be from close to the Albian/Cenomanian boundary – possibly from Zone 6a. There is thus strong evidence for a Cenomanian age for some of the Upper Greensand in Surrey. An extensive study of the Gault Clay in Kent and Surrey is now in progress and this should help to determine the zonal position of the Upper Greensand where it first appears in the succession near Westerham. Work already completed confirms the Zone 8/Zone 9 dating for the base of the Lower Chalk throughout the larger part of south-east England. The succession in Kent is therefore the only one that displays a relatively complete Lower Chalk succession, although even in that area there are horizons where some removal of material is suspected.

The salient features of the sequences in the SE Province may be summarized as follows:

- i. The sub-*plenus* erosion surface can be traced over the whole of south-east England. It is overlain by an almost uniform succession of marls and chalks (Beds 1–8).
- ii. The mid-Cenomanian non-sequence is shown to be a very significant horizon, at which there is evidence of a pause in sedimentation, warping and erosion.
- iii. The Zone 9/Zone 10 non-sequence represents a widespread break in the succession, although on a smaller scale than the mid-Cenomanian non-sequence.
- iv. The Albian/Cenomanian boundary is a complex junction which is almost transitional in some places but represents a marked hiatus at others.
- v. The Chert Beds contain no dateable elements, are overlain by Cenomanian sands and chalks, and underlain by greensands which contain *Stoliczkaia dispar* faunas in the derived condition.

b. South-west Province

This includes the mid-Cretaceous of the counties of Dorset and Devon, and a small area of southernmost Somerset. The successions have been the subject of much controversy in recent years (see discussion of Kennedy 1969). The dominant lithology in the area is that of the Upper Greensand, which presents problems in itself. Fossils of any kind are rare, and those that are found are generally long-ranging species of little stratigraphic value. The major micropalaeontological problem is the collection of fresh material. Most sections of the Upper Greensand are decalcified to some depth, and when fresh material is found it usually proves too hard for satisfactory processing. Acid must be used and the micropalaeontologist has to rely on the glauconitic casts and mineral infillings of foraminifera which have to be identified by comparison with normally preserved material. In the Haldon Hills, however, silicified foraminifera and ostracods have been brushed from the outer surfaces of some of the cherts, and some idea of the microfauna has been obtained. These factors preclude comprehensive micropalaeontological analysis of samples from the area and gaps in our knowledge still remain.

The SW Province is bordered to the east by the Mid-Dorset Swell and to the south-west by the margin of the Cenomanian sea. As it is fairly well defined it is appropriate to begin with a discussion of the eastern margin, running from Buckland Newton towards Swanage.

1. The Mid-Dorset Swell; the Chalk and the Basement Bed

The succession at Buckland Newton, shown in Fig. 21, p. 76, is of Upper Greensand, with its phosphatized *S. dispar* Zone fauna, overlain by some 25–30 m of Lower Chalk. The Chalk succession belongs in Zone 13, with only its lowest levels containing a fauna more akin to that of Zone 12. The phosphate Basement Bed yields elements of Lower Cenomanian faunas as well as the

more important Middle Cenomanian (*Turrilites costatus* assemblage) fauna. This complete admixture of Lower and Middle Cenomanian faunas, combined in an uppermost Middle Cenomanian matrix, indicates the importance of the mid-Cenomanian non-sequence at this locality.

Over the whole of the area, exposures in the mass of the Lower Chalk are rare, while those of the Chalk Basement Bed are relatively abundant. This is due to the marked break in slope at the junction of the chalk and greensand, which, over the greater part of Dorset, is produced by the hardness of the uppermost bed of the Upper Greensand – the Eggardon Grit – which tends to form a prominent ledge. Although the Basement Bed varies in age across the region previous workers have made very little use of this fact. Kennedy (1970) recognized that it became generally younger westwards, but his diagram (1970 : fig. 19) disregards the distribution of his localities. When studied systematically an overall pattern emerges. The main trends are shown in Fig. 27. Drummond (1970 : fig. 10) attempted to demonstrate a relationship between these sedimentological trends and underlying structures, and although no direct relationship between these structures and Lower and Middle Cenomanian depositional patterns is yet established, one is suspected. There are indications of a very slight trough (?) (Fig. 28) in the vicinity of Maiden Newton and the Hooke Valley. This can be followed through Evershot, ST 578050 (Fig. 29), where the Chalk Basement Bed includes a phosphatized *Turrilites acutus* assemblage fauna, to Standers Mill Plantation, SY 587976 (Fig. 30), marking the beginning of the rapid reduction in thickness of the Lower Chalk which continues as far as Chard and Chardstock. Between Standers Mill Plantation, White Sheet Hill, ST 493025 (Fig. 31), Horn Hill, Beaminster, ST 470032

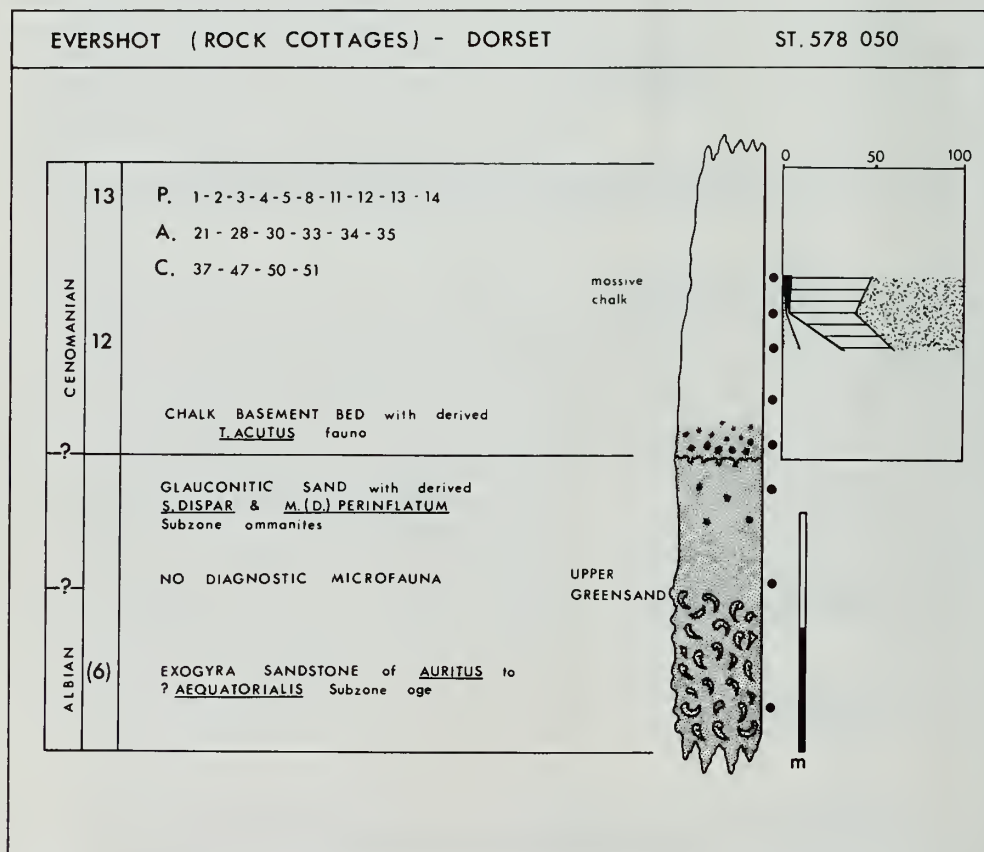


Fig. 29 Microfaunal details, Evershot, Dorset. The ornament used in the planktonic/benthonic ratio graph is explained on Fig. 12c. See Fig. 20 for explanation of letter code.

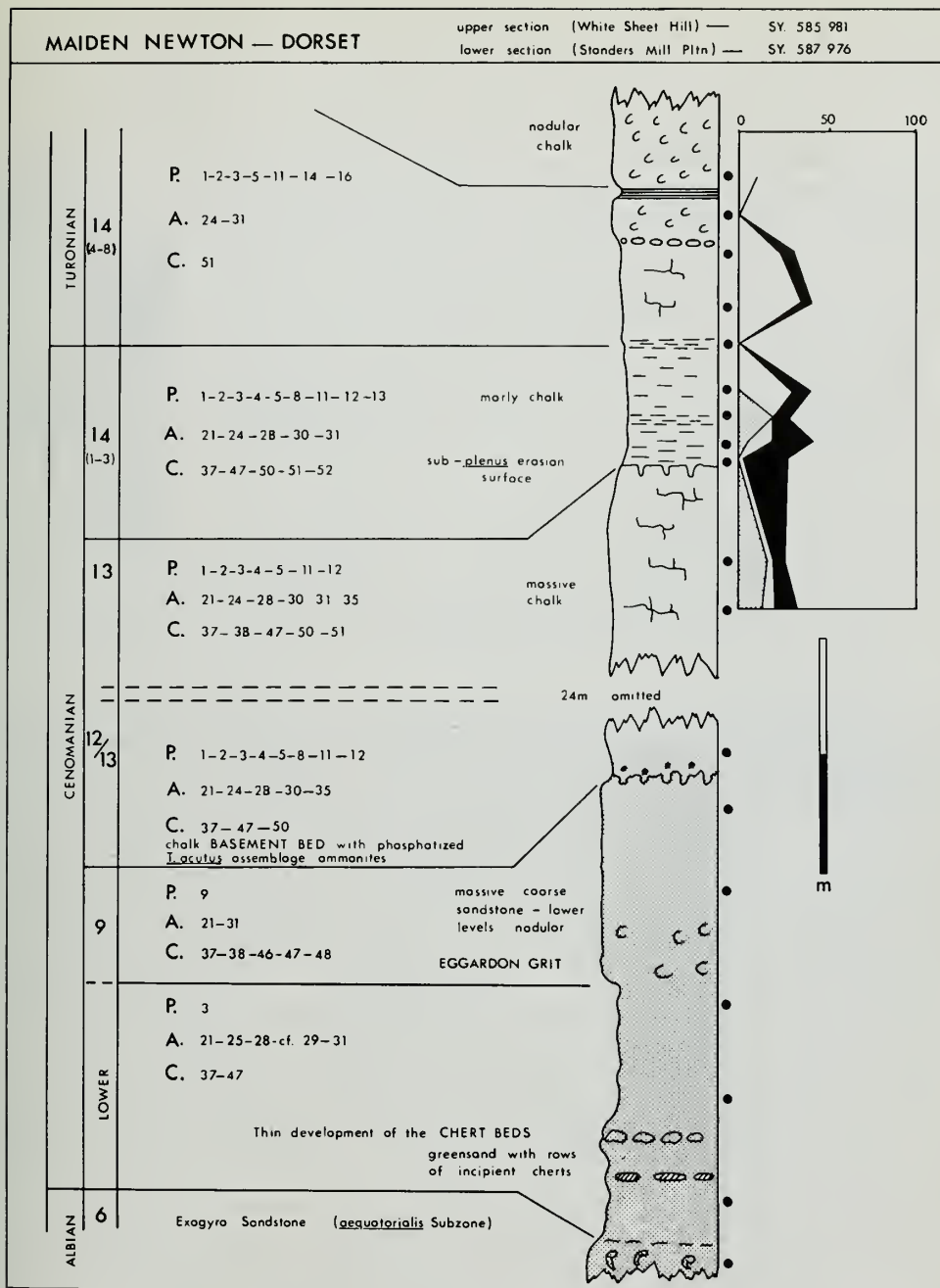


Fig. 30 Microfaunal details, Maiden Newton, Dorset. The ornament used in the planktonic/benthonic ratio graphs is explained in Fig. 12b. See Fig. 20 for key to letter code.

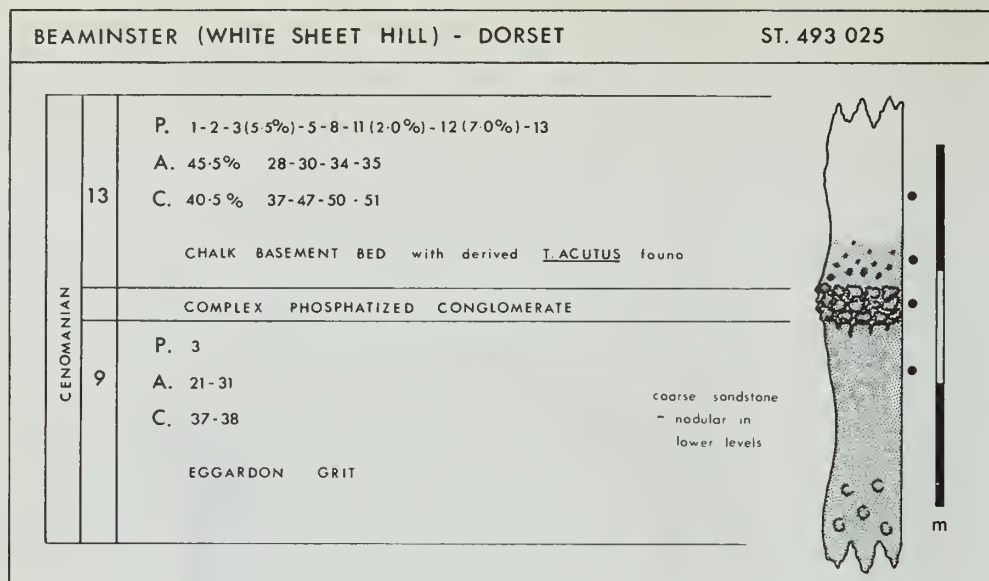


Fig. 31 Microfaunal details, White Sheet Hill, Beaminster, Dorset. See Fig. 20 for key to letter code.

(Fig. 32), and Warren Hill, Crewkerne, ST 404103 (Fig. 33), a complex, phosphatized conglomerate is present below the Chalk Basement Bed. From Warren Hill to the most westerly locality of this traverse is little more than 16 km, but there are three more sections in the area important to our understanding of the stratigraphy. These are at Snowdon Hill, Chard, ST 313089 (Fig. 34), Storridge Hill, Chardstock, ST 316044 (Fig. 35), and Membury, ST 276042 (Fig. 36). Membury is particularly important since the fauna of the old disused quarry section is very well known. While faunal data is available for all the exposures mentioned above, too thin a section is present to permit a determination of the exact position of the Basement Bed within Zone 13. At Membury the Basement Bed is overlain by glauconitic chalk, which in turn is succeeded by approximately 15 m of white, splintery chalk (Fig. 36). The complex ammonite faunas from this sequence have been discussed by Kennedy (1970), who claimed that both Lower and Middle Cenomanian faunas are represented in the Basement Bed. He placed the unphosphatized fauna of the glauconitic matrix in the Upper Cenomanian and we accept this suggestion. The white, splintery chalk contains a microfauna remarkably similar to that of the Frétevou Chalk of the type Turonian, as described by Butt (1966), although the macrofauna, other than *Inoceramus* sp., is particularly sparse. The base of the glauconitic chalk belongs in the lower levels of the Plenus Marls (Beds 1–3), but even though Bed 4 can be faunally recognized the full thickness of Zone 14 is indeterminate because of the overgrown nature of the quarry.

The Membury succession indicates that in this area deposition above the mid-Cenomanian non-sequence began with the Plenus Marls, thus accounting for the great variety of ammonites in the Basement Bed. The sequence indicated by the microfauna is almost identical to that recorded from Bettrechies (northern France) by Robaszynski (1971). The area south-west of a line drawn south-eastwards from Membury (Fig. 27) shows the Cenomanian Limestones, which include as their uppermost member Bed C, the marginal equivalent of the Plenus Marls. The relationship of Bed C to the Plenus Marls can be demonstrated at the Pinnacles, SY 220879 (Fig. 37), and the Bovey Lane Sandpit, SY 217900 (Fig. 38). These localities are discussed later.

The more southerly traverse along the Dorset coast westwards from Swanage is shown in Fig. 39. The Lower Chalk of this coastline is relatively straightforward, and is commonly reduced to a thickness of a few metres by intense Tertiary shearing. At Lulworth Cove and Durdle Door

the Basement Bed can be dated adequately (Zones 11(ii) and 12 respectively) and the pattern of the more northerly traverse is repeated. Eggardon Hill, SY 540950 (Fig. 40), and Askerswell, SY 529923, are the most westerly localities at which the Lower Chalk can be seen on this traverse, and in the latter its thickness is between 8 and 12 m. The next Cenomanian locality in a westerly direction is at Humble Point where the Cenomanian Limestone occupies this interval.

It is concluded that the Lower Chalk succession above the mid-Cenomanian non-sequence was deposited by a transgression over the eroded surface of the Lower and Middle Cenomanian, and all the determinable sedimentation trends appear to be subparallel to the edge of the Mid-Dorset Swell; see Fig. 27.

(cont. p. 98)

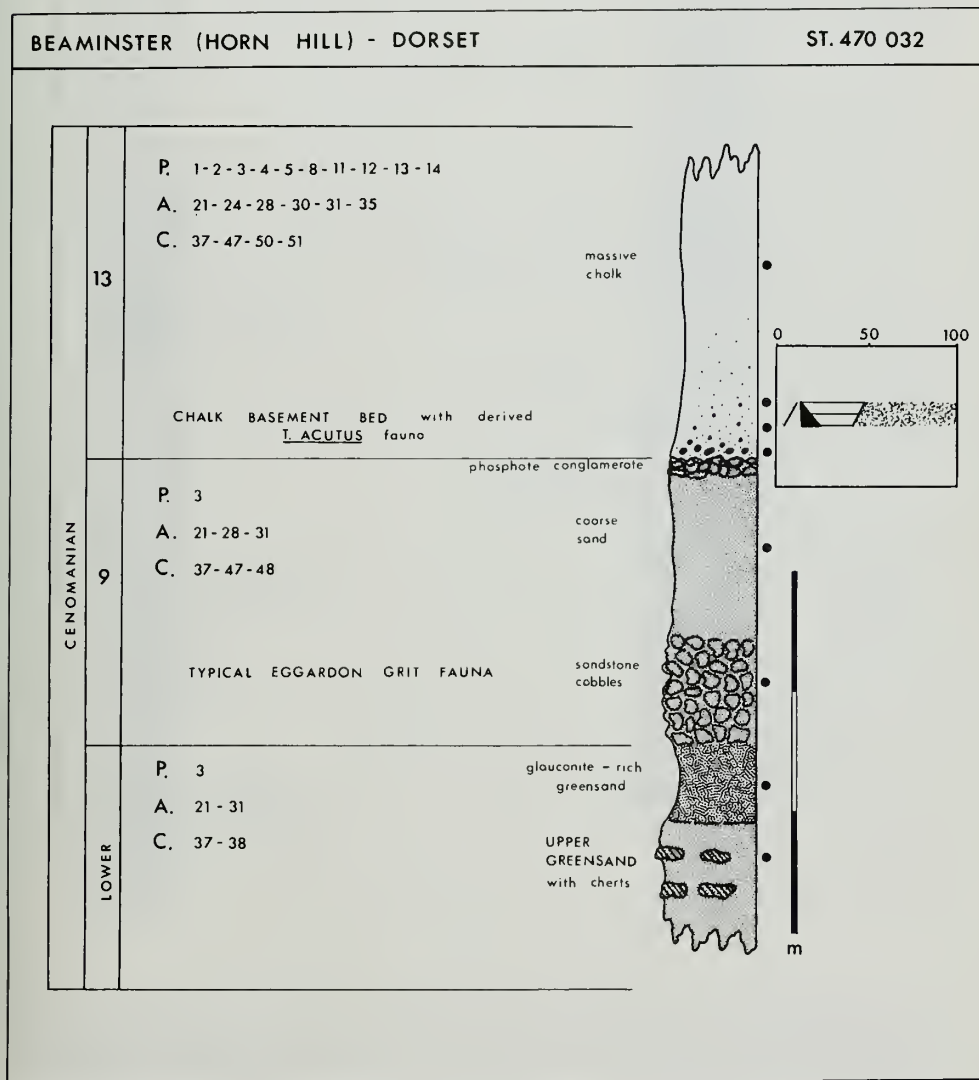


Fig. 32 Microfaunal details, Horn Hill, Beaminster, Dorset. The ornament used in the planktonic/benthonic ratio graph is explained on Fig. 12c. See Fig. 20 for key to letter code.

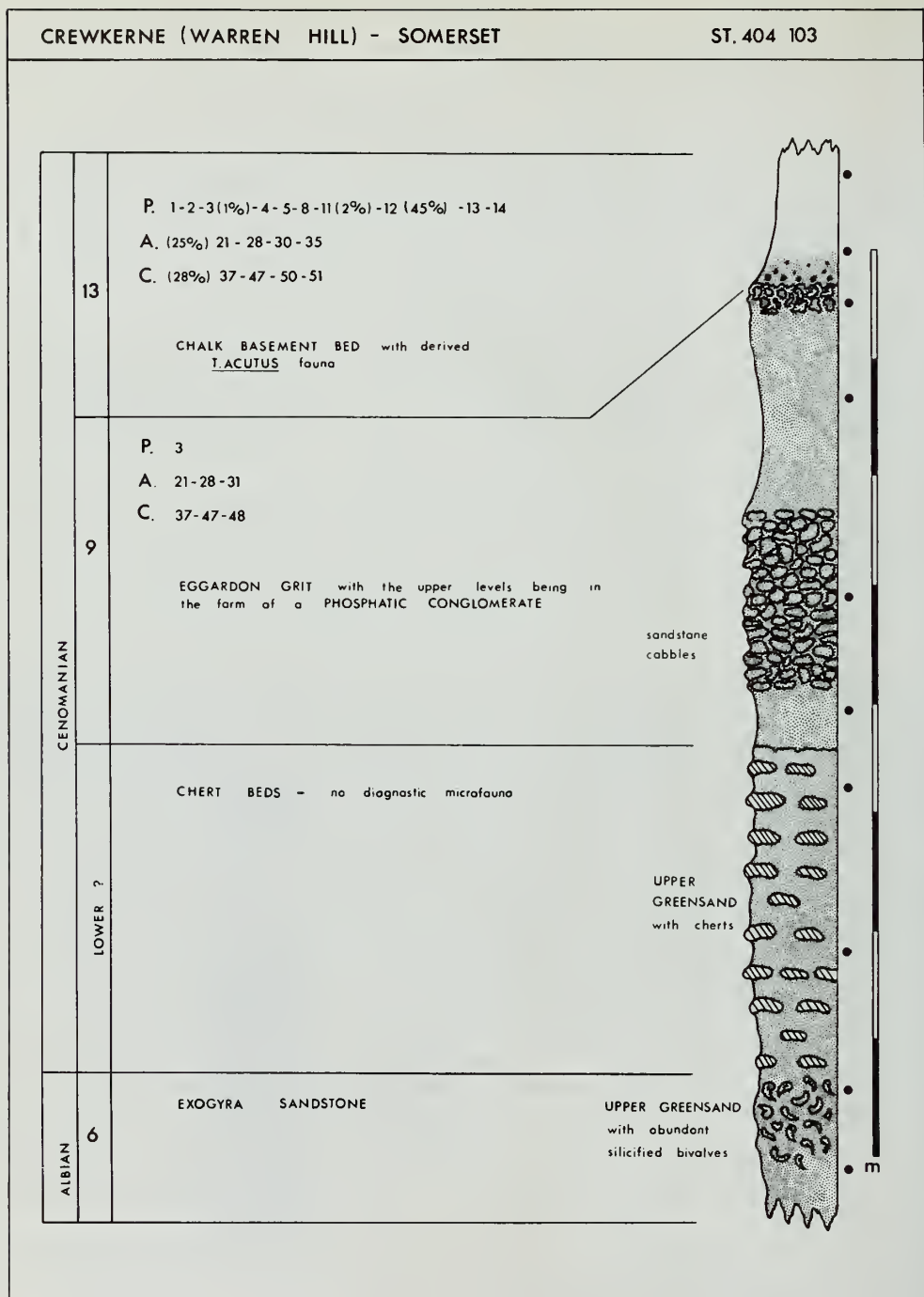


Fig. 33 Microfaunal details, Warren Hill, Crewkerne, Somerset. See Fig. 20 for key to letter code.

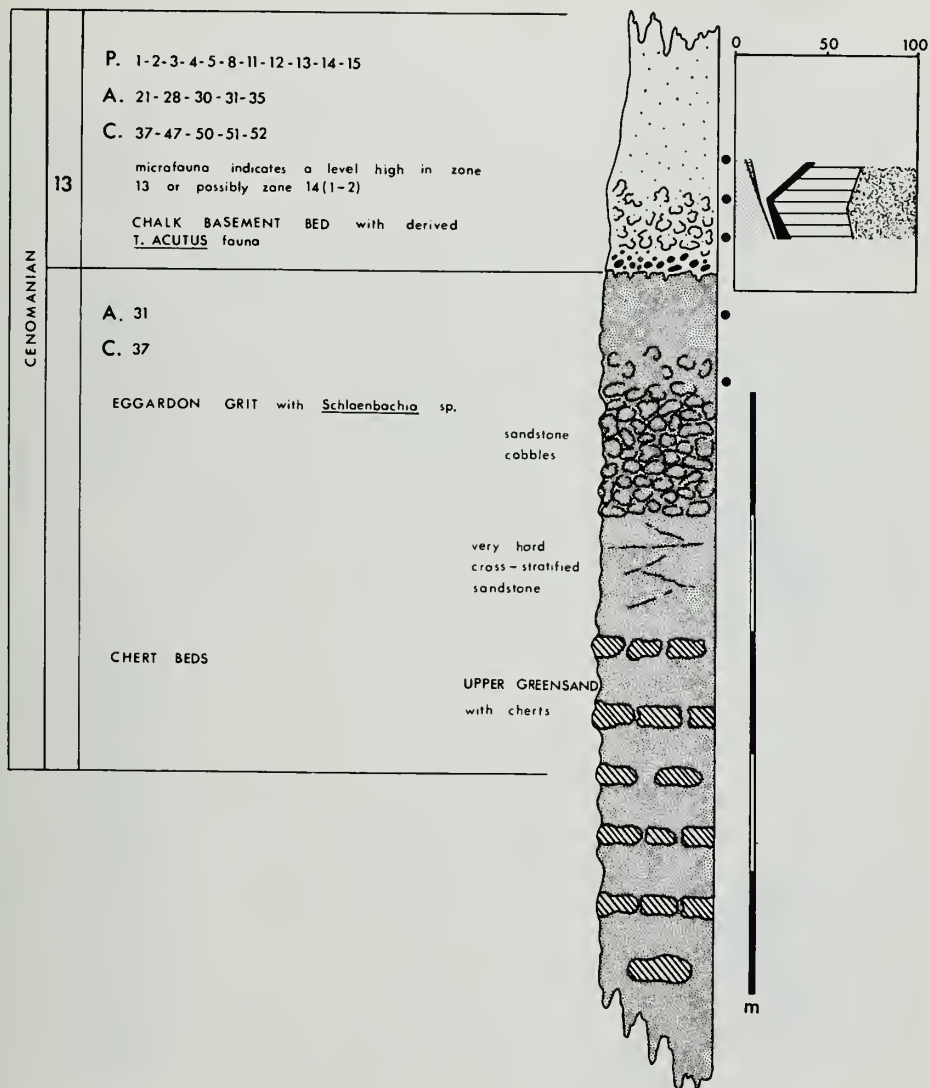


Fig. 34 Microfaunal details, Snowdon Hill, Chard, Somerset. The ornament used in the planktonic/benthonic ratio graph is explained in Fig. 12c. See Fig. 20 for key to letter code.

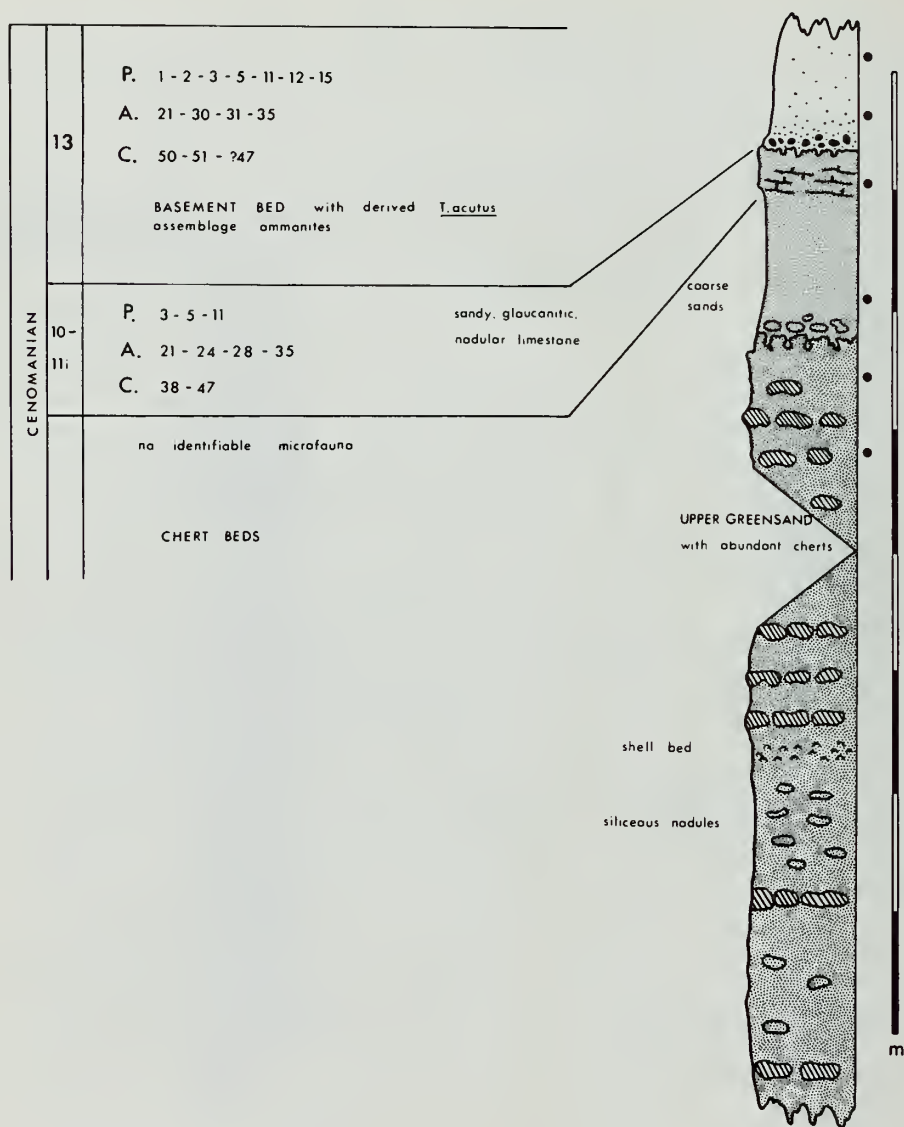


Fig. 35 Microfaunal details, Storridge Hill, Chardstock, Devon. See Fig. 20 for key to letter code.

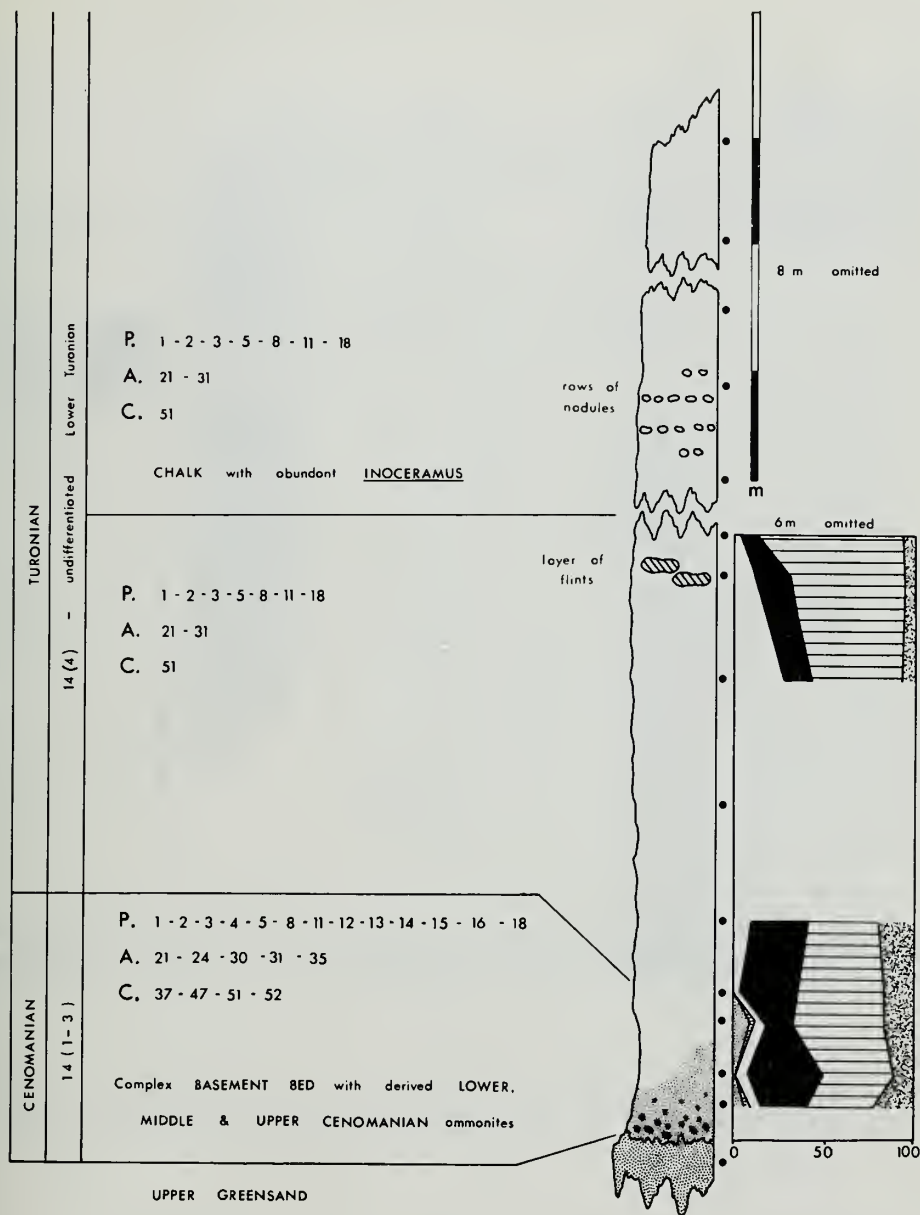


Fig. 36 Microfaunal details, Membury, Devon. The ornament used in the planktonic/benthonic ratio is explained in Fig. 12c. See Fig. 20 for key to letter code.

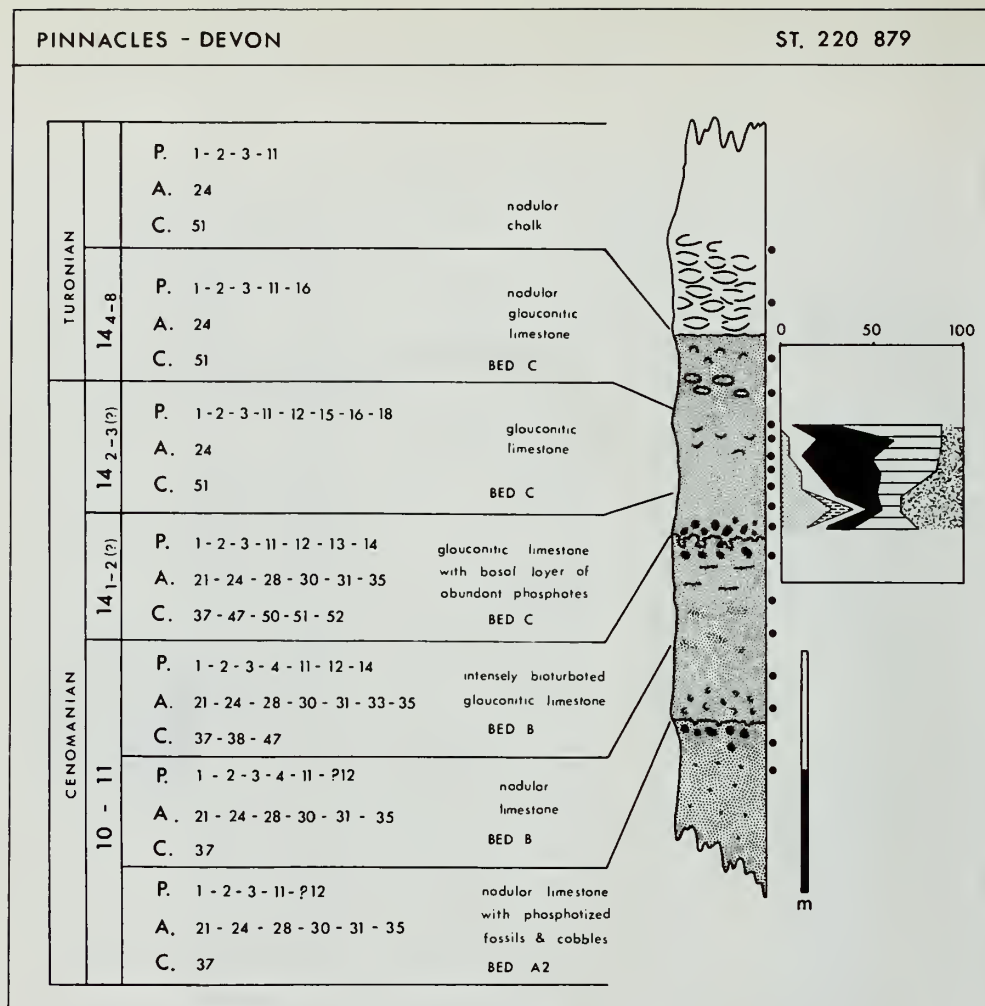


Fig. 37 Microfaunal details, The Pinnacles, Little Beach, Branscombe, Devon. The ornament used in the planktonic/benthonic ratio graph is explained in Fig. 12c. See Fig. 20 for key to letter code.

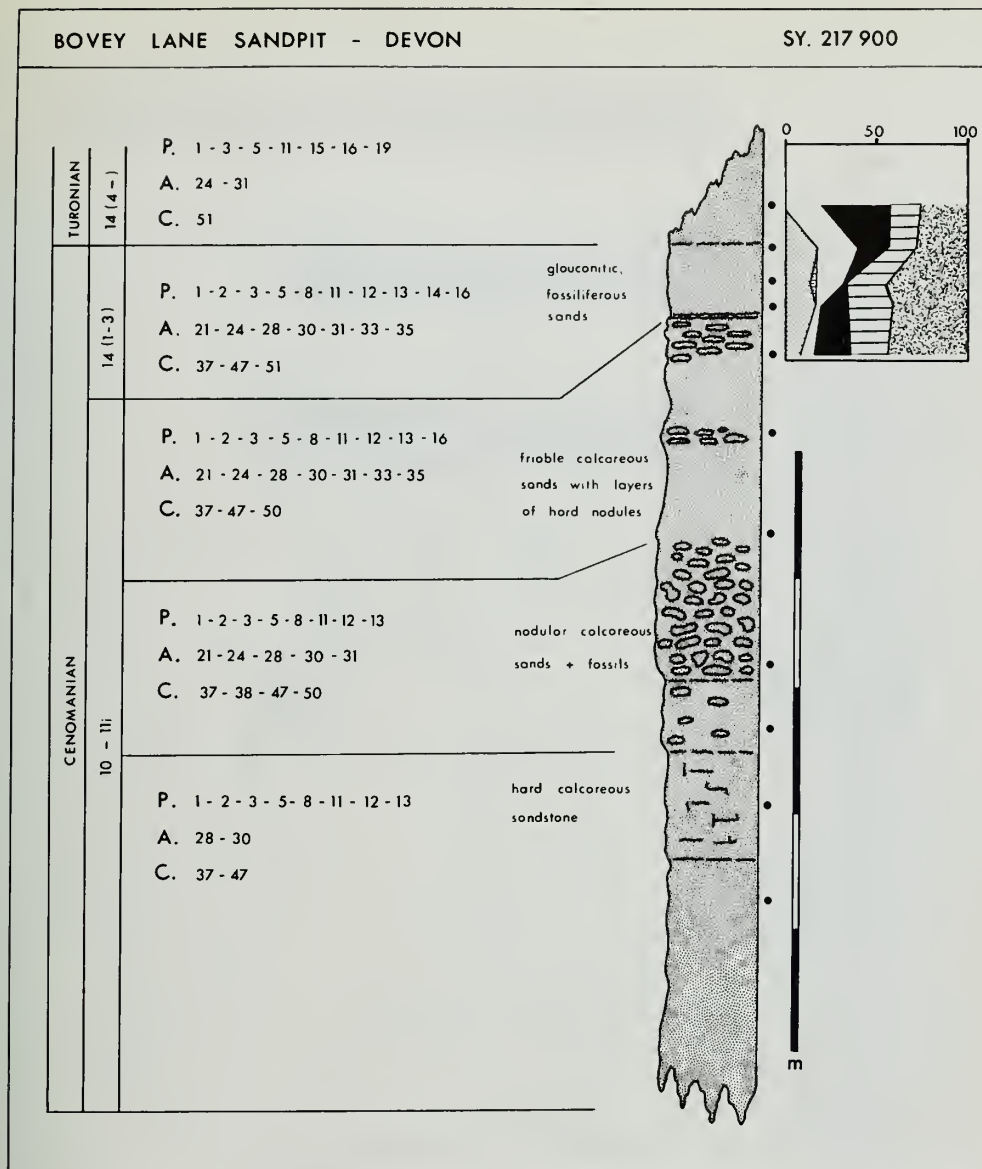


Fig. 38 Microfaunal details, Bovey Lane Sandpit, Beer, Devon. The ornament used in the planktonic-benthonic ratio graph is explained in Fig. 12c. See Fig. 20 for key to letter code.

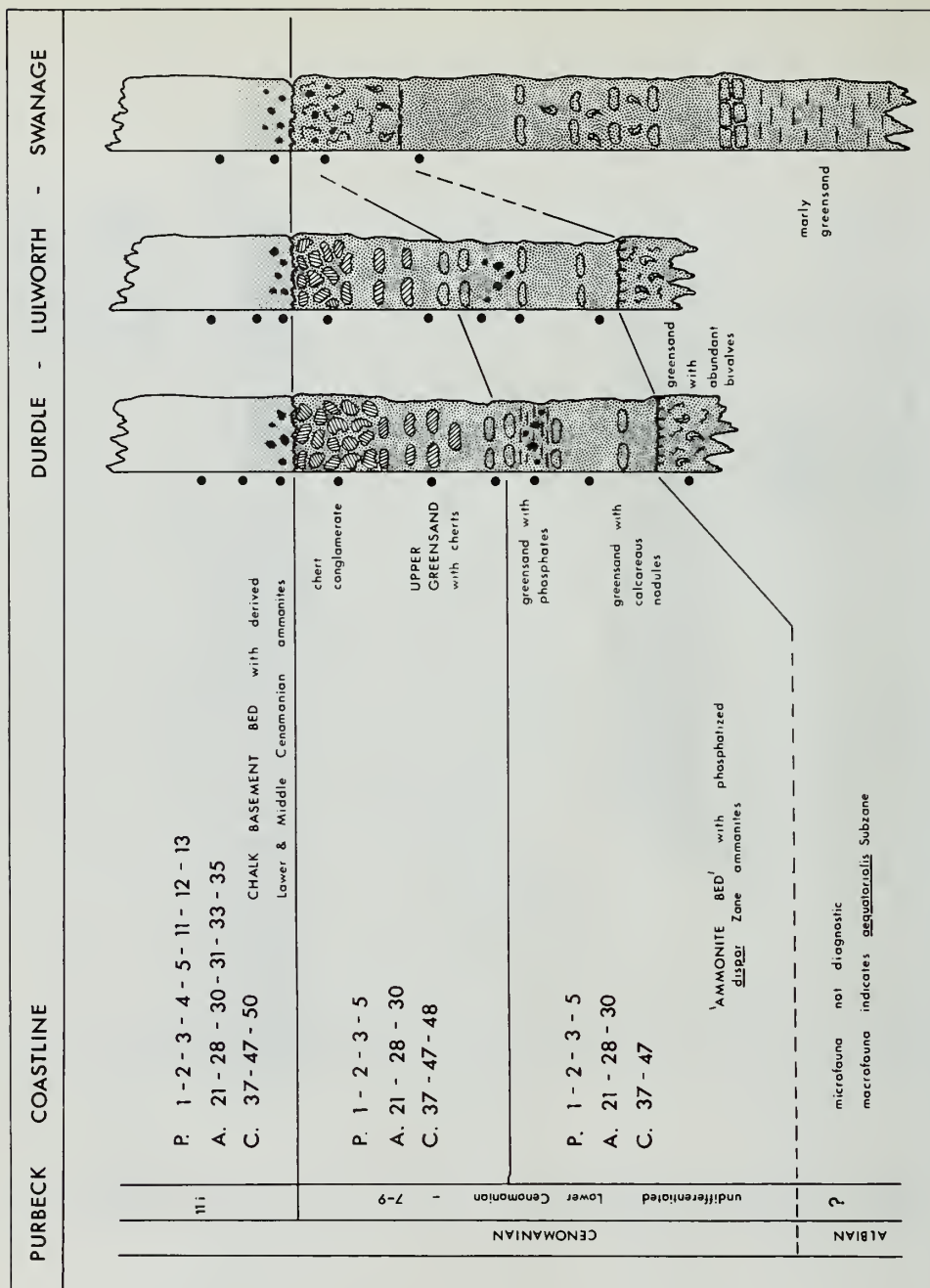


Fig. 39 Microfaunal details, Purbeck coastline. See Fig. 20 for key to letter code.

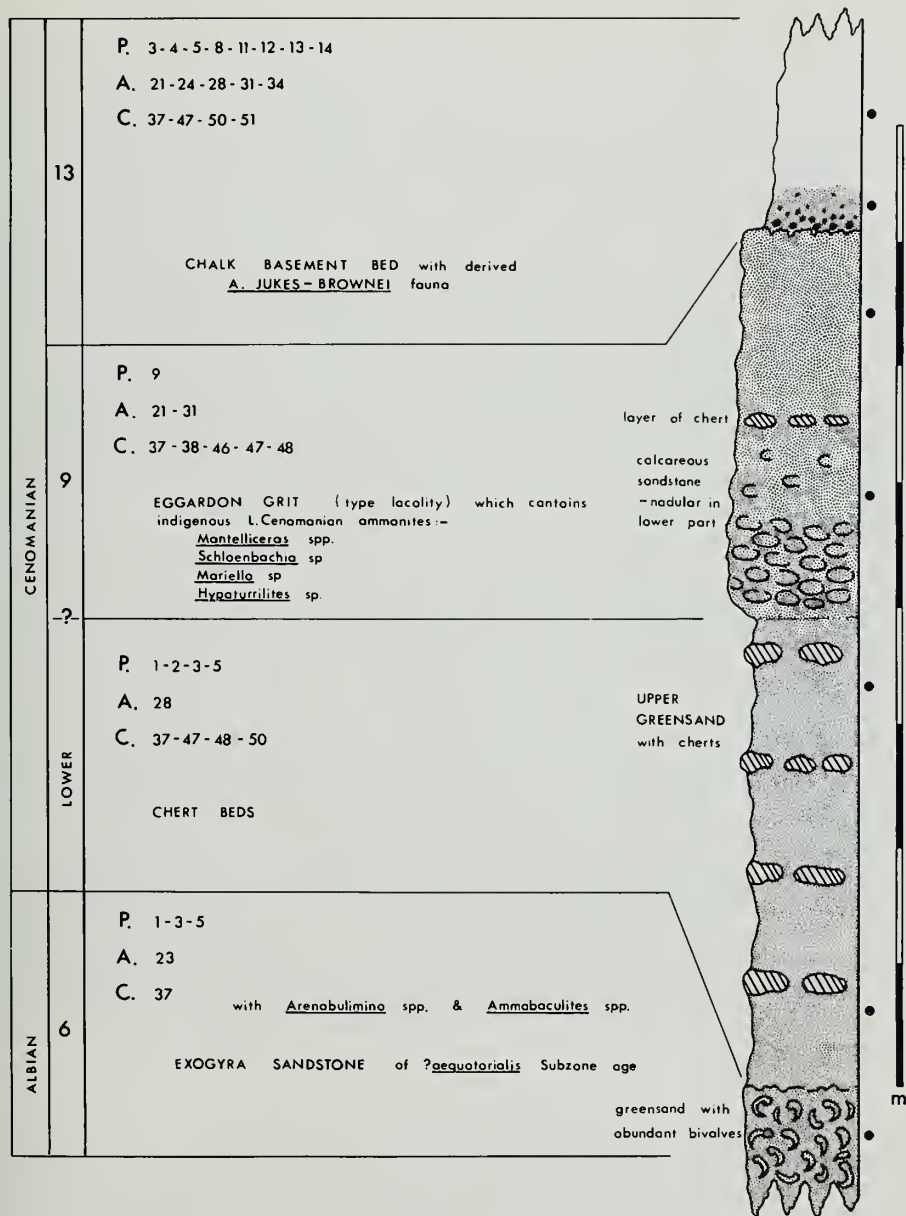


Fig. 40 Microfaunal details, Eggardon Hill, Dorset. See Fig. 20 for key to letter code.

2. The margin of the Mid-Dorset Swell (the Upper Greensand)

The succession below the mid-Cenomanian non-sequence presents none of the essentially simple trends that characterize the overlying Lower Chalk. The grits, sands, and sands with cherts forming this succession display a complex series of relationships frequently complicated by the presence of erosion surfaces.

West of Buckland Newton, where the uppermost Upper Greensand contains a phosphatized *S. dispar* Zone fauna, changes occur which become more important as the Hooke Valley is approached. Only two exposures of any note occur between Buckland Newton and Standers Mill Plantation, the first being at Great Head, ST 624045, and the second at Evershot (Fig. 29). At Great Head an *S. dispar* Zone fauna, similar to that at Buckland Newton, was recorded by Wilson *et al.* (1958). Between Great Head and Evershot the *Exogyra* Sandstone appears. This is a very rough, glauconitic sandstone, full of silicified bivalves, and a very useful field marker horizon. It has yielded an unphosphatized specimen of *M. (Mortoniceras)* aff. *commune* Spath and has been recorded as of *auritus* or *aequatorialis* Subzone age (Kennedy 1970: 630). The greensand above the *Exogyra* Sandstone at Evershot has yielded phosphatized *S. dispar* Zone ammonites, although specimens are rare. The changes initiated at Evershot are continued in the river bank exposure at Standers Mill Plantation (Fig. 30), where both the 'Chert Beds' and the Eggardon Grit appear in the succession. The Chert Beds, with only small incipient siliceous concretions, occur between the Eggardon Grit and the *Exogyra* Sandstone. The Eggardon Grit was initially described from Eggardon Hill by Wilson *et al.* (1958), although many earlier workers have called this distinctive horizon the 'Calcareous Sandstone'. It is usually a very hard, glauconite-free, calcareous sandstone which, at several localities, has yielded Lower Cenomanian ammonites. As no contradictory evidence is forthcoming, it is now accepted as being of Lower Cenomanian age – Zone 9 in the microfaunal succession. The sparse microfauna from the *Exogyra* Sandstone suggests that the Upper Albian dating is probably correct. Although the evidence is not conclusive, the sands, which include the cherts at Standers Mill Plantation, contain faunal elements indicating a Lower Cenomanian age. Along the line of the Hooke Valley the Chert Beds thicken only slightly, but when traced south-westwards they thicken markedly. An additional complication is introduced along the Hooke Valley, where a distinctive bed of phosphatized cobbles and fossils is found between the Eggardon Grit and the Chalk Basement Bed. The fauna of the phosphate conglomerate is entirely Lower Cenomanian. The majority of the ammonite species present are also recorded from the phosphate bed seen on the Isle of Wight (Fig. 25) at the Zone 9/Zone 10 boundary. The dating of the Eggardon Grit as Zone 9 is in accord with the ammonite distribution. The phosphatized conglomerate can be traced the whole length of the Hooke Valley and is last seen at Warren Hill. It represents a hiatus of some magnitude, covering Zones 10–12 of the Cenomanian. This hiatus is related not only to that of the Zone 9/Zone 10 boundary in the Isle of Wight, but also the base of the Chalk in the Mere area. The Popple Bed and the Rye Hill Sands (Warminster Greensand) are therefore lateral equivalents of the Eggardon Grit, although the exact relationship is difficult to determine. It is also relevant to note the distribution of *Orbitolina lenticularis* at this time, occurring in the Rye Hill Sands, the lower levels of the Eggardon Grit at Wilmington and in the cliffs at Dunscombe (south Devon). The significance of *O. lenticularis* will be discussed later.

3. The South-western Shelf (Cenomanian Limestones)

Westwards from Warren Hill the Cenomanian Limestones and Sands first appear in the succession. The mid-Cenomanian non-sequence beneath Bed C (the marginal equivalent of the Plenius Marls) represents a hiatus which began in the Cenomanian (between the *Turrilites costatus* and *T. acutus* Assemblage Subzones of Kennedy 1969), while the underlying Eggardon Grit has been assigned to the Lower Cenomanian Zone 9. The Cenomanian Sands and Limestones therefore cover the whole, or a part of, Zones 10–11(i). In terms of the ammonite successions this would approximately equate with the *Mantelliceras dixonii* and *T. costatus* Assemblage Subzones of south-east England. The faunas of these sands and limestones have been studied in the sections at Chardstock (Fig. 35), Hutchins Pit, Wilmington, ST 216003 (Fig. 41), White Hart Sandpit,

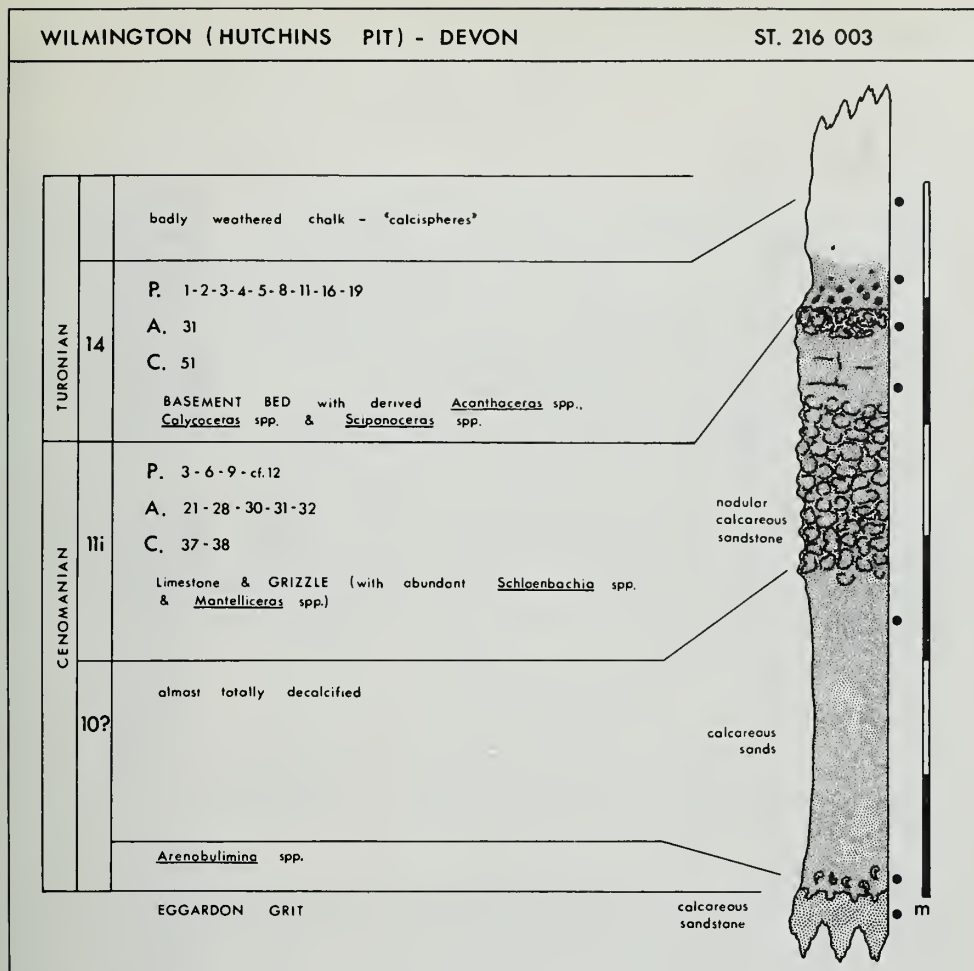


Fig. 41 Microfaunal details, Hutchins Pit, Wilmington, Devon. See Fig. 20 for key to letter code.

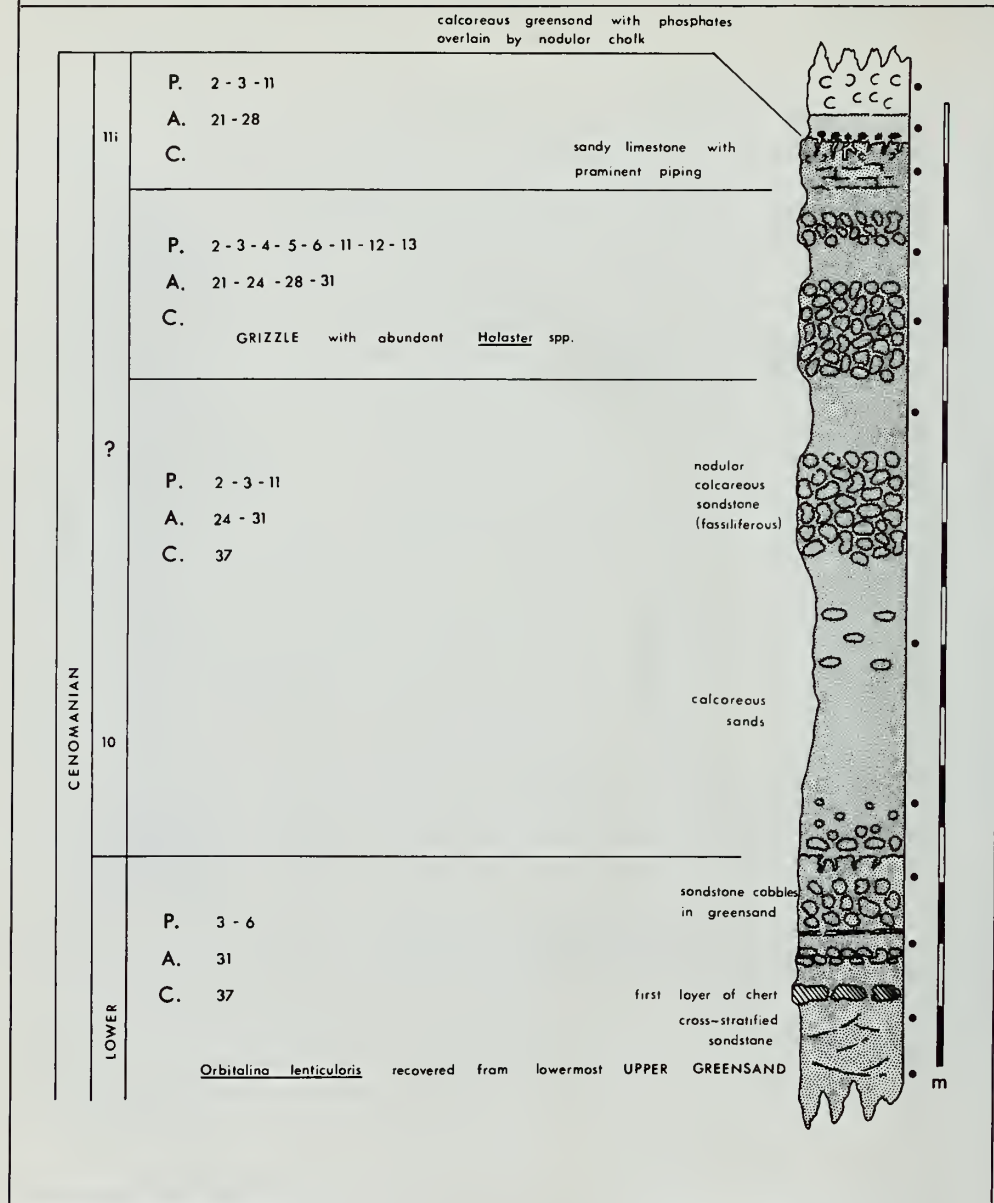


Fig. 42 Microfaunal details, White Hart Sandpit, Wilmington, Devon. See Fig. 20 for key to letter code.

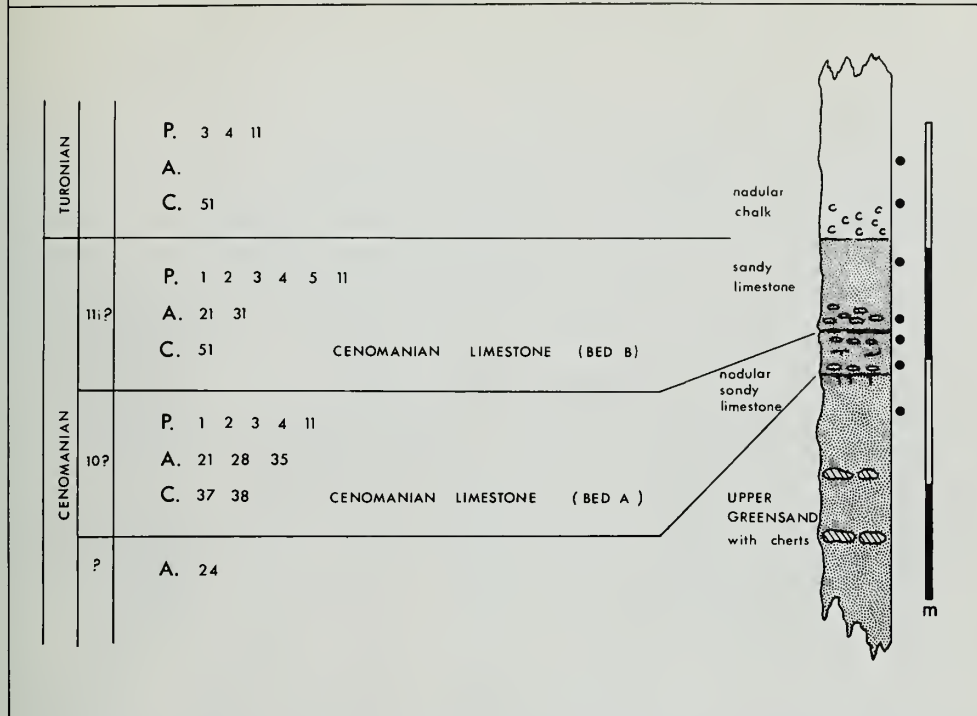


Fig. 43 Microfaunal details, Beer Beach, Devon. See Fig. 20 for key to letter code.

Wilmington, SY 208999 (Fig. 42), the Pinnacles, Branscombe (Fig. 38), Beer Beach, SY 229890 (Fig. 43), and Bindon Cliff, SY 278897 (Fig. 44). The lithology and stratigraphy of these beds were described in detail by Smith (1957a, etc.) and Kennedy (1970) and only new evidence will be presented here. Although processing is very difficult, several of the zonally important species, including planktonic forms, have been recovered from most of the important sections. The faunas agree almost entirely with the predicted position between the Zone 9/Zone 10 and Zone 11(i)/Zone 11(ii) boundaries. The only feature of particular interest is the appearance of many planktonic forms – far more than would be expected at this level in the succession. Their occurrence will have to be considered in the light of regional studies of the palaeogeography. The presence of *Plectina cenomana*, *Arenobulimina advena*, *P. mariae*, *Gavelinella intermedia*, *G. baltica*, *G. cenomanica*, *Guembeltria harrisi*, *Hedbergella delrioensis*, *Praeglobotruncana stephani*, *H. washitensis*, and rare *Rotalipora cushmani* indicates a position in Zone 11(i). Although *P. cenomana* has not been recorded from Bed A1 or A2 of the Cenomanian Limestone succession (or from the sands at Wilmington) it cannot be assumed that this necessarily proves the presence of Zone 10 in the lower part of the succession. While it would be most satisfactory if this could be demonstrated, conclusive evidence is lacking. The ammonite faunas occur as rolled pebble-fossils and phosphatized casts and are not reliable. When inspected under short wave ultraviolet light these ammonites fluoresce bright yellow, indicating the presence of uranium, taken up with the phosphates which formed during exposure on the sea floor (Bromley 1965). The fauna of the lower limestone unit (Beds A1 and A2) is remarkably like that of the phosphate conglomerate of the Hooke Valley. This is not surprising as these two ammonite faunas accumulated during the same interval of geological time. Kennedy regarded this fauna as indicative of the *Mantelliceras saxbii* Assemblage Subzone of south-east England, although this age must refer to the faunal elements,

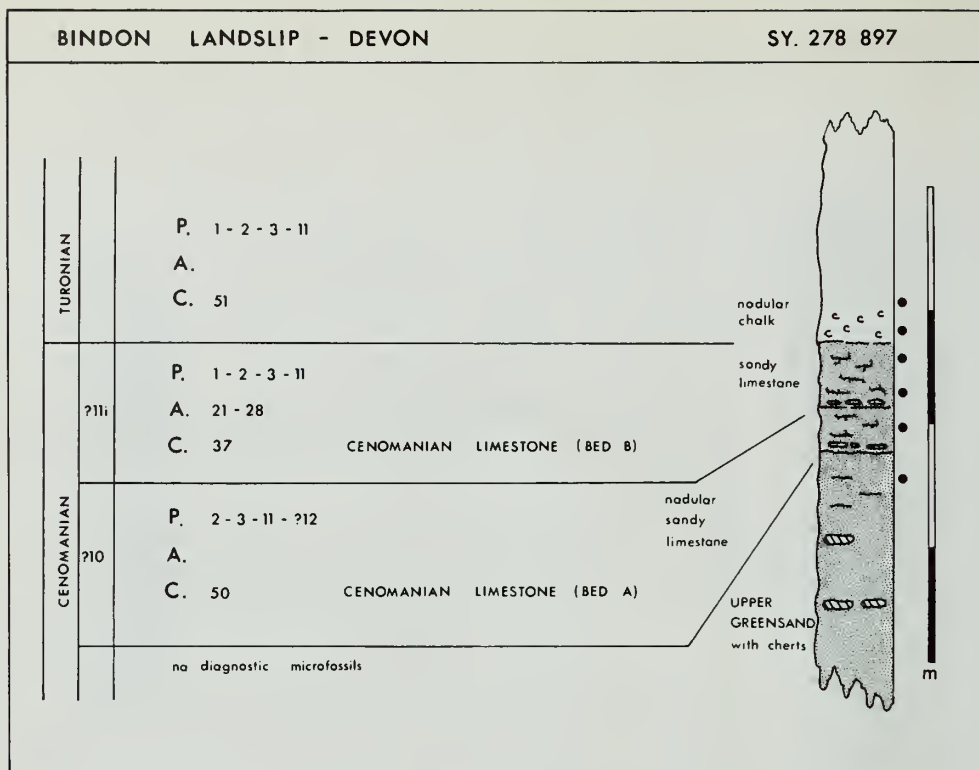


Fig. 44 Microfaunal details, Bindon Landslip, Devon. See Fig. 20 for key to letter code.

and not necessarily the enclosing sediment. The underlying Eggardon Grit (or Top Sandstones) is thought to belong to Zone 9 (? = *M. saxbii* Assemblage Subzone), and a derived *M. saxbii* assemblage fauna would be expected to occur in the overlying beds, which on the microfaunal content of the matrix are dated as Zone 10 (?). The upper limestone bed (Bed B) contains a poor ammonite fauna with elements from the *M. dixonii* assemblage. This derived fauna, together with the abundant *Holaster subglobosus* (Leske) encountered at this level, indicates a position in the Middle Cenomanian. This agrees with the Zone 11(i) dating of the microfauna. The microfauna is sparse but further work should add to the already extensive faunal lists.

The original suggestion of Hart (in discussion of Kennedy 1969) that the Cenomanian Limestones were of Upper Cenomanian age has, by further research, been shown to be incorrect. The warping and erosion below the Cenomanian Limestones, initially described by Smith (1957a, etc.) had been equated with the warping below the mid-Cenomanian non-sequence. This correlation was based on the abundance of planktonic microfauna in these sands and limestones. At that time the extent of the Zone 9/Zone 10 non-sequence was not fully appreciated and its effect beyond the Isle of Wight had not been considered. The determination of the trends which affect the beds below the mid-Cenomanian non-sequence proved beyond doubt that those of the flexures below the Cenomanian Limestones belonged to an earlier phase in the geological development of the area. The trends below the lower non-sequence determined by Smith are at a distinct angle to those immediately below the mid-Cenomanian break, and therefore cannot belong to the same suite. The interpretation put forward here differs from that given by other workers in this area in that the movements are ascribed to a level within the Lower Cenomanian and not immediately below the Albian/Cenomanian boundary.

4. The South-western Shelf (the Upper Greensand)

The succession below the mid-Cenomanian non-sequence exposed along the coast from Swanage to Branscombe (Devon) is closely similar to that in central Dorset. The lithological elements are almost identical, although there is some variation in their spatial relationships. The whole of the Upper Greensand will be dealt with, the uppermost levels being considered first. Sections on the Purbeck coast have been described in great detail by Wright (*in* Arkell 1947) and the included fauna is exceptionally well known. In central Dorset faunal evidence is sparse.

Wright (*in* Arkell 1947) demonstrates the presence of Albian *Hysterocheras orbigny*, *H. varicosum*, *Callioplites auritus* and *Mortoniceras aequatorialis* Subzones at various localities—all within the Upper Greensand succession. This faunal sequence is recorded below the *Exogyra* Sandstone and no indication is given of the age of this bed itself. Kennedy (1970: 630) places it in the *aequatorialis* or *auritus* Subzones in central Dorset. This distinctive unit is remarkably constant both in appearance and subzonal position over a considerable part of central and southern Dorset. Its placing relative to the rest of the uppermost greensand succession of the Purbeck coast is shown in Fig. 45. However, the succession above the *Exogyra* Sandstone is more relevant. As at Standers Mill Plantation the Chert Beds appear above this level. On the coast the sands with cherts, which thicken rapidly westwards, are capped by a chert conglomerate, which immediately underlies the Chalk Basement Bed. The most important faunal horizon is the 'ammonite bed', traceable over a considerable length of coastline. The occurrence of this horizon led previous workers to record the *S. dispar* Zone in every section. It is interesting that the *Arrhaphoceras substuderi* Subzone has never been found at any locality. Wright (*in* Arkell 1947: 184–185) lists the ammonite fauna and comments: '... and of these some are confined to Dorset, some are

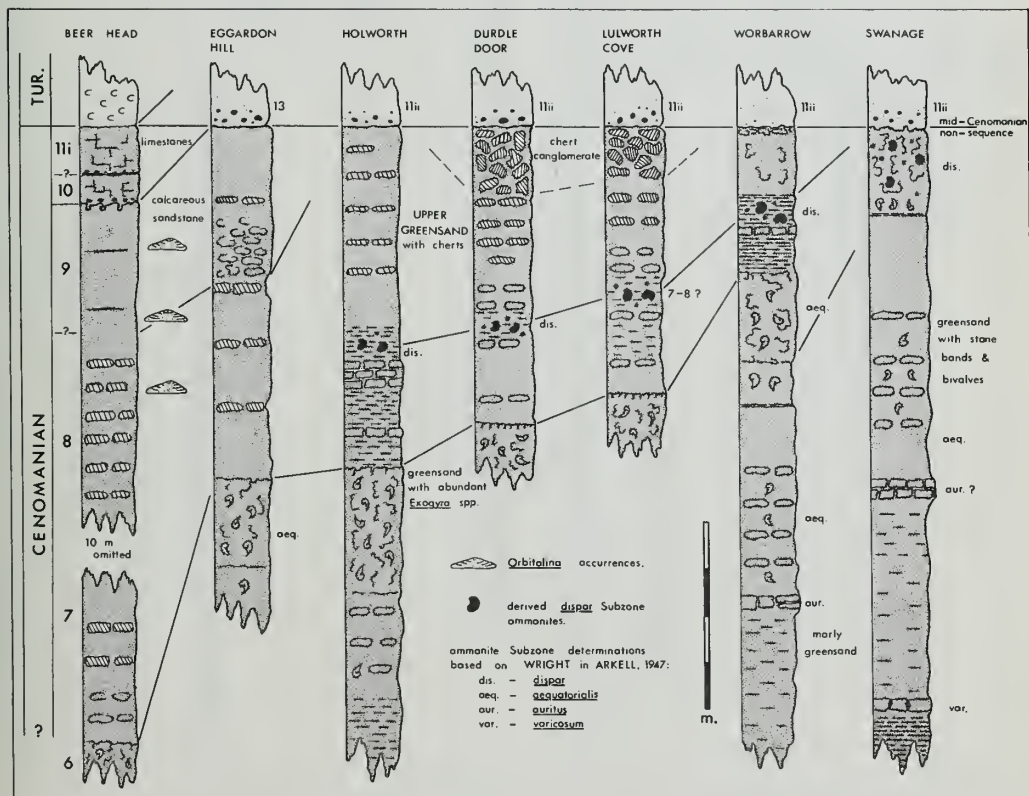


Fig. 45 A correlation of the uppermost Upper Greensand of the Dorset-Devon coastline.

members of the semi-derived Cambridge Greensand fauna, and by their occurrence in Dorset can be placed stratigraphically.'

We have studied the relevant sections in detail and emphasize the following points, all of which suggest a different interpretation.

- i. The ammonites found are all phosphatized.
- ii. Most specimens of *Mortoniceras* sp. we found had been broken before phosphatization.
- iii. The microfauna of the 'ammonite bed' includes *Marssonella trochus* (d'Orbigny), *Tritaxia pyramidata*, *Arenobulimina advena*, *Dorothia gradata* (Berthelin), *Gavelinella cenomanica*, *G. intermedia*, *Lingulogavelinella jarzevae*, *Heterohelix moremani*, *Guembelitria harrisi*, *Hedbergella delrioensis*, and *Praeglobotruncana stephani*/P. *delrioensis*, which indicates a horizon quite foreign to the Upper Albian. While some of the key species are absent there, the evidence suggests a position in the Lower Cenomanian (Zones 7-9).

Except that *Arenobulimina anglica*, *Marssonella ozawai* and *Flourensina intermedia* are missing the microfauna of the ammonite bed is almost identical with that described from the Cambridge Greensand. Although the value of the ammonite bed fauna is not clear cut it is suggestive of

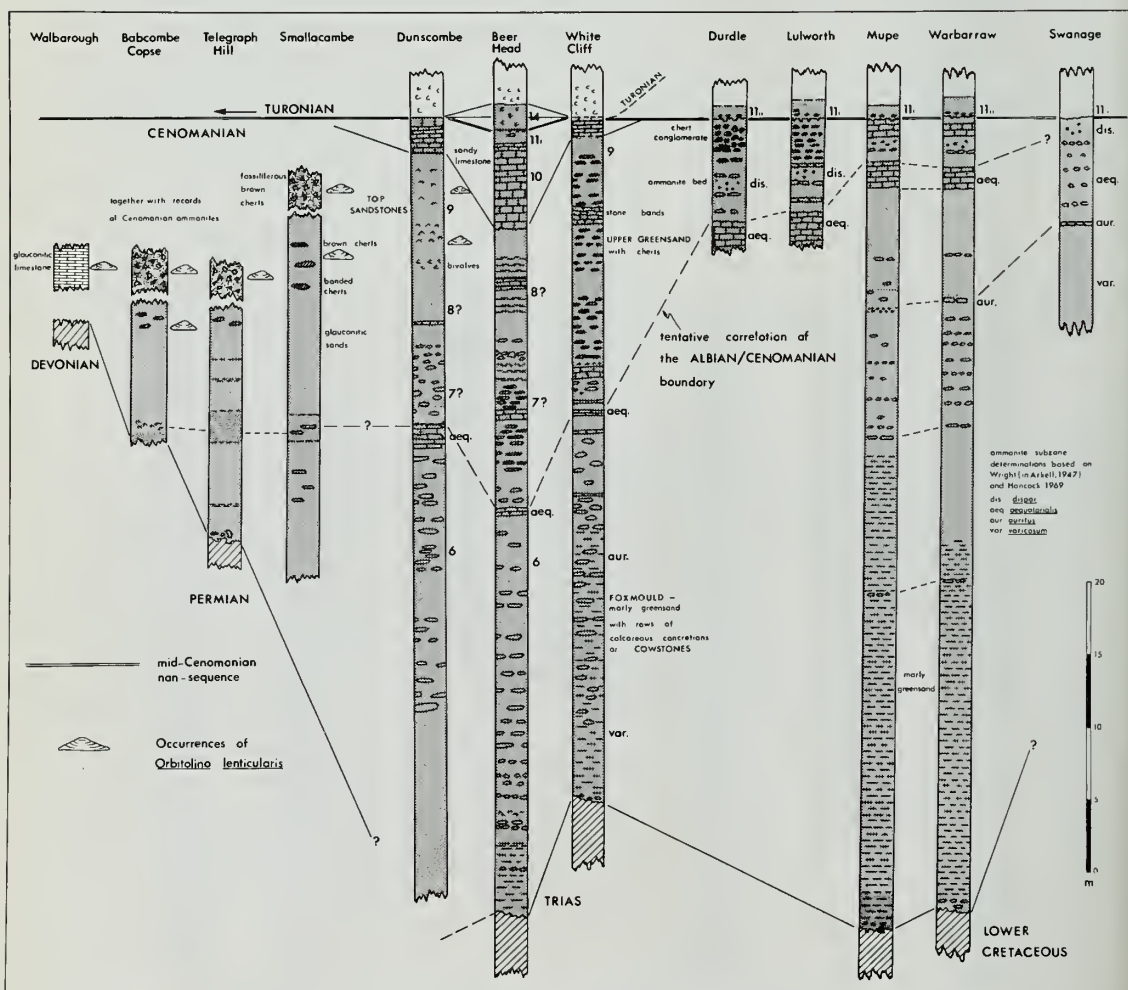


Fig. 46 A correlation of the Upper Greensand and associated strata along the south coast of England from Swanage (Dorset) to Newton Abbot (Devon).

conditions and age very like those pertaining in Cambridgeshire (Hart 1973a). While Wright uses the Dorset fauna to place the Cambridge fauna stratigraphically, we regard the 'ammonite bed' fauna, like the 'Cambridge' fauna, as totally derived. However, the *Exogyra* Sandstone underlying the 'ammonite bed' can be placed in the *auritus/aequatorialis* Subzone, indicating a greater hiatus than that developed in Cambridgeshire.

The Upper Greensand successions of Dorset and Devon are given in Fig. 46, which also includes the sections just discussed. The conclusions based on examination of the latter also apply to the whole cross-section. However, in south-east Devon there is also a substantial thickness of 'Top Sandstones', which have already been correlated with the Eggardon Grit, and shown to belong in the Lower Cenomanian. The chert conglomerate seen at Lulworth and Durdle Door is absent from Devon, and it is suggested that this concentrate, formed prior to the deposition of the Chalk Basement Bed, represents the Zone 10–Zone 11(i) interval (i.e. the Cenomanian Limestones of Devon). The upper levels of the Chert Beds and the whole of the Top Sandstones on the Devon coast yield specimens of *Orbitolina lenticularis* (our own collections; see also Jukes-Browne (1900: 208) and the specimens P.43429 in the British Museum (Natural History)). These occurrences of *Orbitolina* can be traced through Wilmington and into the Rye Hill Sands of the Warminster area. In the latter a Cenomanian dating is agreed by all workers. The microfauna from the 'ammonite bed' of the Purbeck coast, as well as that from the Chert Beds at Standers Mill Plantation, indicate that the orbitolines from the Chert Beds are of Lower Cenomanian (Zones 7–8) age, and that the overlying Top Sandstones occupy the Zone 9 interval. The fauna of the Foxmould supports this determination: we have found Upper Albian faunal elements in it, although the actual zonal indicators are absent. The main objection to this dating relies on the much-quoted specimen of *M. (Mortonicerias)* of *stoliczkaia* type found in the Chert Beds near Charmouth (Kennedy 1970: 642; Wilson *et al.* 1958: 148; Spath 1933: 423). Even if the provenance and identification of this specimen are accepted it is suggested that one ammonite from a single horizon is inadequate evidence for dating a whole formation covering the greater part of south-west England. This specimen's value is lessened by the presence of an abundant, derived *S. dispar* Zone fauna at approximately the same level to the east of Charmouth.

When the Cretaceous succession is traced westwards from Beer it becomes appreciably thinner until its only representative west of the River Exe is the series of sands and cherts forming the Haldon Hills. These beds, in part, appear to be the lateral equivalent of the Chert Beds of Dorset and SE Devon, although this relationship has yet to be confirmed palaeontologically. Hart (1971) suggested that the *Orbitolina lenticularis* fauna could be used for this purpose. As other evidence must also be considered and some of the sections in the Haldon Hills are not very well known, additional description is necessary.

The locality at Wolborough (Newton Abbot) was rediscovered by Dr R. A. Edwards during the I.G.S./Exeter University (1966–69) revision of the Teignmouth (Sheet 339) 1" Geological Map. Although small and badly exposed it provides the only definite record of limestones from the Upper Greensand of the Haldon and Bovey areas (Fig. 47). These limestones are coarse-grained, sandy and glauconitic, and occur as blocks associated with shelly, glauconitic sands 400 m south of the church (SX 855699) at Wolborough. The section is only seen along a field boundary and its position in the succession is not certain, but recent excavations by Hamblin & Wood (pers. comm., and in press) in the Greensand sequence have revealed further details of the succession, and some firm correlations will soon be available. However, since the samples were collected only 4.5–5.0 m from an exposure of Devonian slates, it may be inferred that these limestones are very low in the local succession. To the north of Newton Abbot no limestones are seen in any part of the succession and the beds with *O. lenticularis* come from much higher levels in the sequence (see Fig. 46). The localities to the north of the Bovey Basin were first described by Godwin-Austen (1842). Later workers (Woodward 1876, Pengelly 1865) were unable to locate these sands and gravels precisely. Reid (1898) found them, but as they were close to the Bovey Basin they were ascribed to the Eocene. Jukes-Browne & Hill (1903) demonstrated the presence of Cenomanian fossils in the cherts found in the gravels at Aller Vale, and used them to postulate the presence of the Cenomanian sea in the Haldon area. The most useful locality at present is the large working sandpit operated by Kingston Minerals Ltd at Babcombe Copse (SX 869766)

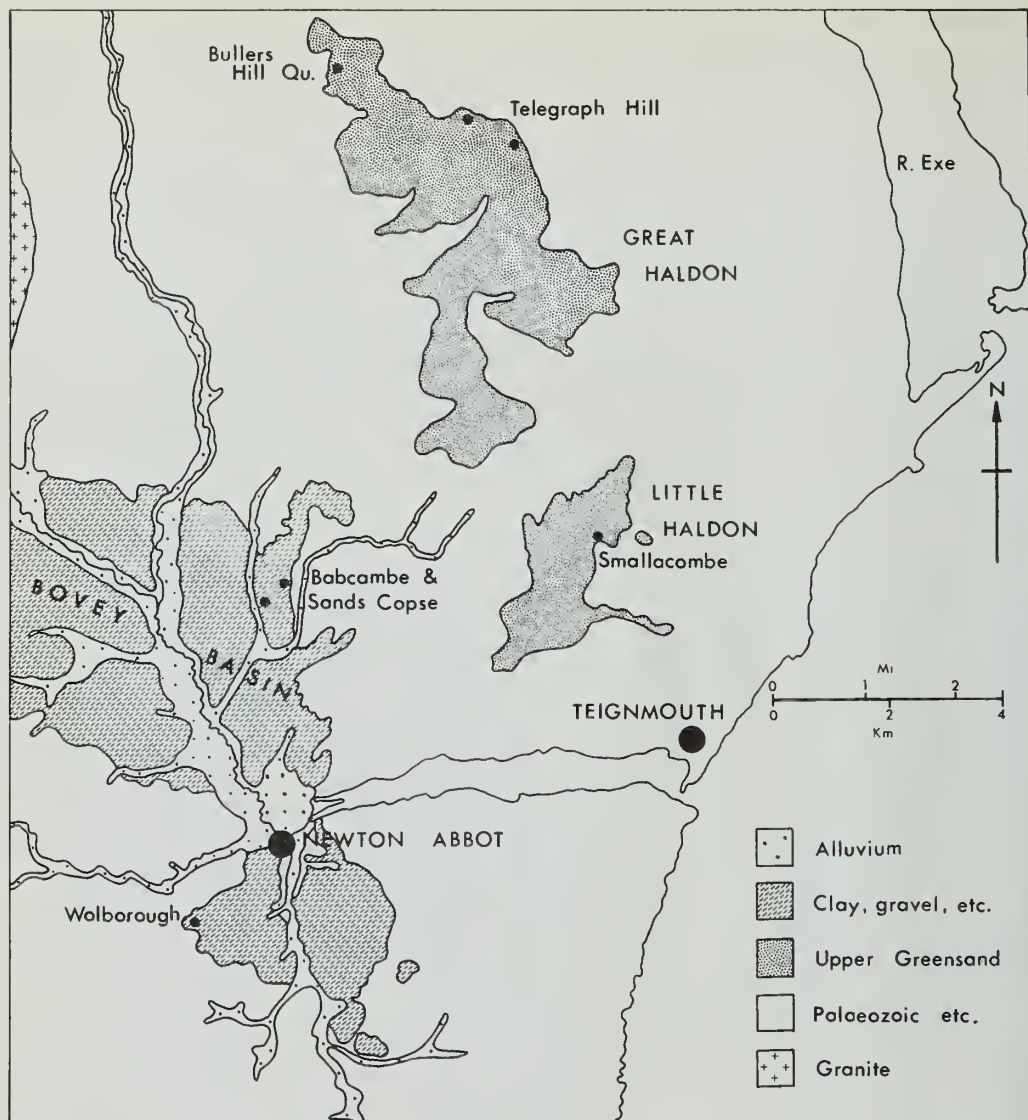


Fig. 47 Cretaceous localities in the Haldon Hills and Bovey Basin, south Devon. The Haldon Gravels (of Eocene and Pliocene age) have been omitted from this figure.

which is 400 m from Babcombe Farm (SX 867769). The lower levels of this pit display a series of gravelly sands which are overlain by slightly finer sands that contain pale grey banded cherts. Littering the floor and the tips of the quarry are brown-grey fossiliferous cherts that cannot be seen *in situ*. These appear to come from the overlying material and therefore cannot be placed in the succession with any accuracy.

The pits at Sands Copse (SX 865759), while providing occasional brown, fossiliferous cherts, are so degraded that no material can be collected *in situ*. At Bullers Hill Quarry (SX 882848) a succession of gravels can be seen resting on decalcified Upper Greensand, which appears to be impregnated with clay wash from above. Pale grey banded cherts can be found *in situ*, while the brown, fossiliferous cherts again litter the floor of the workings. The small pits on Telegraph Hill

described by Jukes-Browne & Hill (1900) have been completely obliterated by the rebuilding of the Exeter–Torrey (A.380) road, although the temporary excavations for the main cutting allowed an inspection of the full succession down to the New Red Sandstone. A second phase of excavations for the Exeter–Plymouth (A.38) road have allowed the confirmation of the Telegraph Hill succession.

While exposures on Little Haldon are very poor, there are some accounts of them in the literature. The section up Smallacombe Goyle (SX 923767) was given in some detail by Jukes-Browne & Hill (1900 : 223). The *Orbitolina* fauna was recorded from the upper levels of the brown cherts, and this occurrence is confirmed here. These cherts appear very similar to those found in Babcombe Copse and therefore give an indication where the latter occur in the regional succession. Jukes-Browne & Hill (1900 : 226) also recorded *O. concava* (Lamarck) from the Basement Sands but this has not been confirmed. The coral fauna was thought by Jukes-Browne to occur in the upper levels of the lowest glauconitic sands in Smallacombe Goyle, and this provides an accurate link with the Blackdown Sands of the Honiton area. This relationship was discussed by Downes (1882) and little work has been done since then. The Blackdown Sands have yielded ammonites which place them in the *varicosum* and/or *orbigny* Subzones (Hancock 1969 : 66). Unfortunately no microfauna can be obtained from this area, as these sands have been totally leached by percolating water owing to the early removal of the overlying chalk.

The relationship of these sequences to those on the Devon coast is shown in Fig. 46, which also indicates the recorded horizons of *O. lenticularis*. It must be emphasized that the majority of specimens of *O. lenticularis* have been obtained from blocks of cherts found on the floors of the various quarries in the area. The only *in situ* records are from Wolborough, where the limestones appear to be at their normal stratigraphic level, and Smallacombe Goyle. This latter occurrence, as already noted, shows the brown fossiliferous cherts in their true stratigraphic position. Thin-section studies of the cherts of both types from this area have proved the *Orbitolina* fauna to be in association with an abundant microfauna, now replaced by chert. *Hedbergella delrioensis* of Cenomanian aspect has been identified, although no zonal forms have been isolated so far. Three ammonites have been found in the brown fossiliferous cherts by Wood (1971 : 100). These have been identified as *Mantelliceras* sp., ? *Hyphoplites* cf. *pseudofalcatus* (Semenow) and *Turritiles* cf. *acutus* Passey – and are an admixture of Lower and Middle Cenomanian forms. While the *Mantelliceras* and *Hyphoplites* agree with our suggested dating of the Chert Beds in south-west England, the occurrence of *T. acutus* is a problem. Kennedy's (1969) *T. acutus* assemblage occurs above the mid-Cenomanian non-sequence, and we cannot explain this occurrence in the cherts. West of a line running south-east through Membury the only horizon in which elements of the *T. acutus* assemblage occur is in the basal layer of Cenomanian Limestone Bed C. This species has never been found in the lower two beds (A and B).

Two other lines of non-micropalaeontological evidence can be used to place the Haldon succession accurately in its stratigraphic position. The three levels at which instability affected the Lower and Middle Cenomanian are as follows:

- i. Basal Cenomanian non-sequence (i.e. the Albian/Cenomanian boundary), which produced the 'ammonite bed' above the *Exogyra* Sandstone.
- ii. The Zone 9/Zone 10 non-sequence, now thought to precede the Cenomanian Limestone succession, equating with the flexuring described by Smith (1957a, etc.).
- iii. The mid-Cenomanian non-sequence which produced the Chalk Basement Bed and the base of Bed C of the Cenomanian Limestone succession.

While Hart (1971) suggested that the folding demonstrated on Haldon by Durrance & Hamblin (1969) equated with the mid-Cenomanian non-sequence, present research has shown that the trends are not compatible with this suggestion. It is more probable that the warping associated with the Zone 9/Zone 10 boundary equates with this level, thus agreeing with the suggestion of Durrance & Hamblin that the folding was early Cenomanian, prior to the deposition of the Cenomanian Limestones. The placing of the upper part of the Haldon succession in the Lower Cenomanian Zones 7–9 would agree with the occurrence of *Orbitolina* as well as two of the ammonites found by Wood.

The second line of evidence reinforcing this correlation results from work (Hart 1973b) with

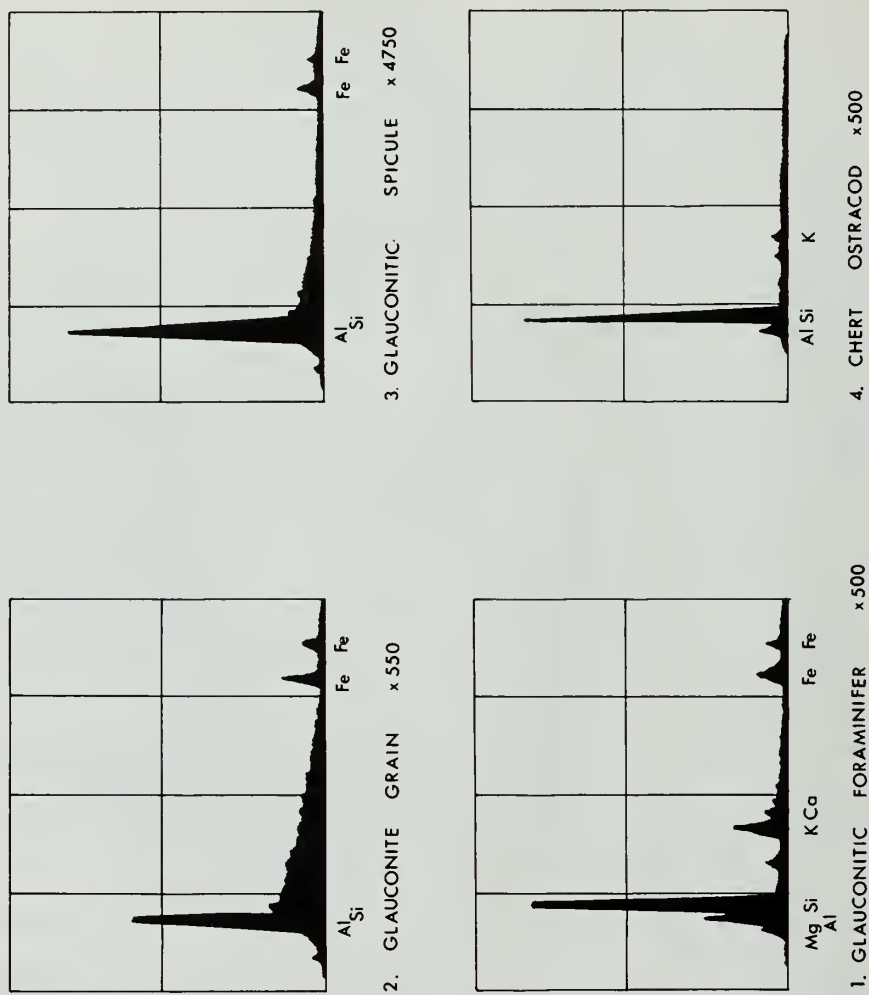


Fig. 48 Geochemical data of specimens from the Upper Greensand.

1. Glauconitic cast of a foraminifer.
2. Grain of glauconite from the sediment.
3. Sponge spicule replaced by glauconite.
4. Ostracod specimen from the cherts.

the Cambridge Instruments Stereoscan Mk II and Nuclear Diodes' EDAX 707 Dispersive X-ray analyser. The following summarizes some of the data from this study. Preliminary work included the analysis of some of the 'glauconitic' casts of foraminifera so commonly encountered in the sands and limestones of south-west England. Until recently substantial quantities of material were required for X-ray analysis, and since only good specimens were retained in our micropalaeontological collections, chemical determinations were not possible. However, the present instrumentation allows the analysis with little, if any, damage to the specimen involved. The profile obtained from one cast of *Rotalipora* from the Cenomanian sands – confirming the belief that the mineral is from the glauconite suite – is shown in Fig. 48(1). To provide a standard profile some glauconite grains from the sediment have also been analysed, and one of these is shown in Fig. 48(2). The glauconite cast is completely different in composition from that recorded in the grain. The most interesting aspect of the comparison is the richness of the cast in silicon. As the infilling of the chambers was presumably a post-depositional feature it is suggested that this is evidence of the presence of Si-rich post-depositional groundwater.

It has been noted that in the same sequence of strata sponge spicules are very abundant at some levels, particularly where beds of chert are lacking. Almost all these spicules have been replaced by glauconite, although the colour is slightly different from that seen in the foraminiferal casts. Analysis of individual spicules (Fig. 48(3)) has shown aluminium-rich glauconite very similar to that forming the mineral grains, and quite unlike anything found in the casts. This possibly indicates that the replacement of Si-rich sponge spicules with Al-rich, Si-poor, glauconite could not belong to the same generation as that found in the casts. The final stage of the investigation was to study the composition of the foraminifera and ostracods brushed from some of the cherts on Haldon. The profile shown in Fig. 48(4) is typical of any of these individuals, and it is interesting to note the occurrence of detectable amounts of potassium, reminiscent of the foraminifera profile in Fig. 48(1).

This analytical work suggests that there have been some substantial changes in the geochemistry of the sediment during diagenesis. The timing of these changes is quite important, and it has been possible to show that the level below which silicification took place was coincident with the mid-Cenomanian non-sequence. While glauconite casts, sponge spicules and evidence of silicification (cherts in the Upper Greensand and beekitization in the Cenomanian sands of Wilmington) are features of the succession up to the level of the mid-Cenomanian non-sequence, they are not seen above it. The effects above the Eggardon Grit (or Top Sandstones) are very slight, the main changes being in the succession below that level (i.e. Zones 7 and 8). This zonal determination coincides with the occurrence of abundant sponges in the Lower Cenomanian in south-east England, which characterizes the Zone 7–8 interval (see Fig. 12 and Fig. 17).

Clearly the question of the age of the Chert Beds cannot finally be decided at present, but it is hoped that the suggestions given above will stimulate further research into their stratigraphic position. Our overall interpretation of mid-Cretaceous stratigraphy in south-west England is not unlike that of many earlier workers (Hancock 1969; Kennedy 1970) and a compilation of both the microfaunal and macrofaunal data should allow a yet more accurate correlation. One fact that stands out in our work is the recognition of the importance of derived faunas. As Hart (1973a) has shown *à propos* the Cambridge Greensand, the presence of a completely diagnostic, but phosphatized *Stoliczkaia dispar* Zone fauna is no guarantee that there is any *S. dispar* Zone in the area. All over the south-west of England it is evident that macrofaunal data provide a succession up to and including the *auritus* and *aequatorialis* Subzones. Above that level the *S. dispar* Zone fossils come entirely from phosphatic concentrations (particularly on the Dorset coast), and are unreliable indicators of the age of the matrix. The *S. dispar* Zone is not at present thought to occur *in situ* in the SW Province, although new work by Hamblin & Wood (pers. comm.) may necessitate a reappraisal of this view.

c. North-east Province

North of the North Norfolk Swell from Hunstanton the mid-Cretaceous sequence is represented by thin, nodular chalk, some of which is pink, yellow, purple and green. Disaggregation of these

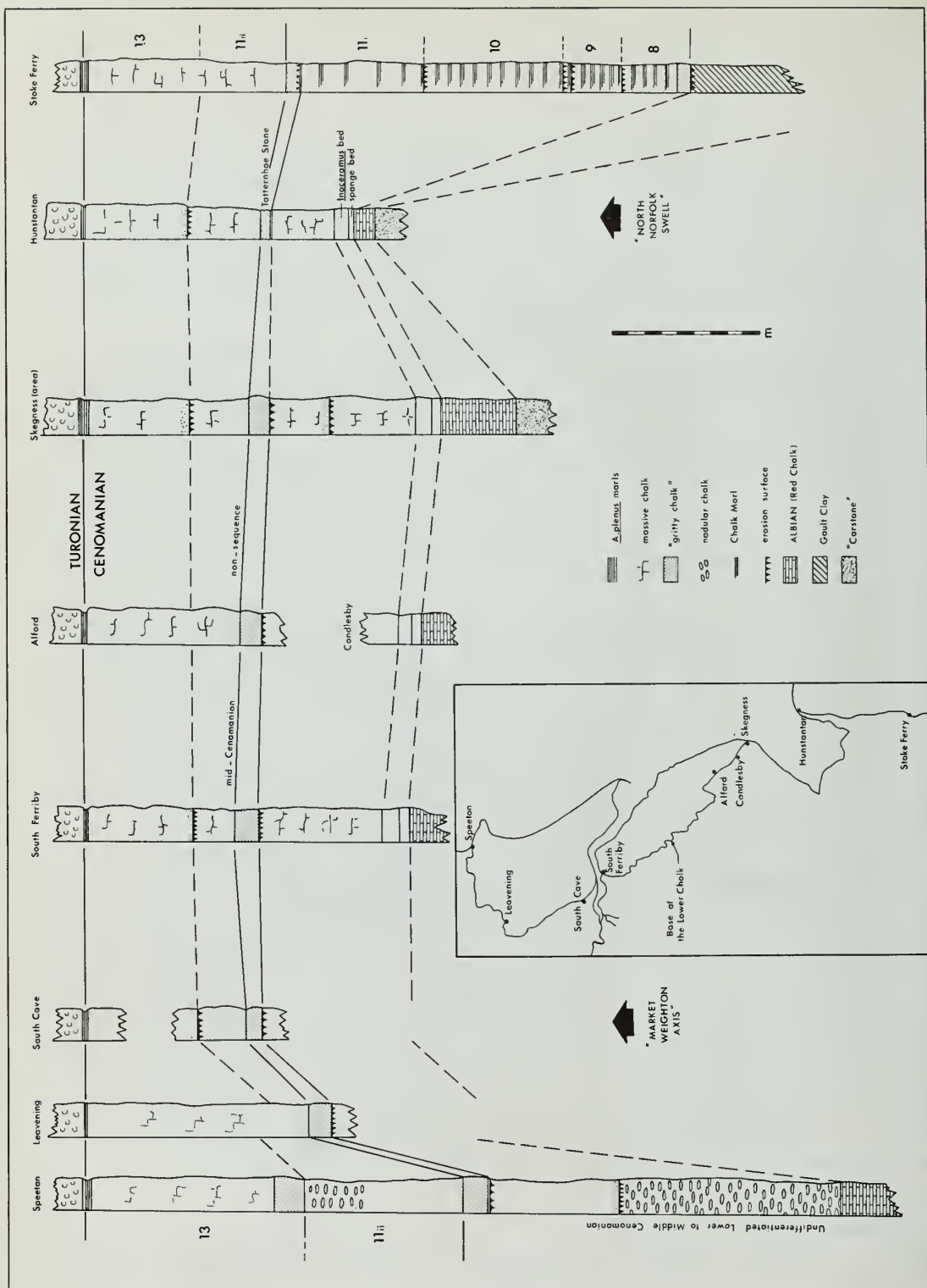


Fig. 49 The correlation of the mid-Cretaceous from Speeton (Yorkshire) to Stoke Ferry (Norfolk).

materials is difficult and detailed micropalaeontological investigation has not been attempted. Some indications of the stratigraphy can be gleaned from the general lithological sequences and the microfaunal data already obtained. The Plenus Marl horizon is used, as in southern England, although the 'Black Band' has not yet yielded any microfauna. The mid-Cenomanian non-sequence can be shown to coincide with the upper surface of the Totternhoe Stone, and is therefore a recognizable horizon. The Totternhoe Stone appears as a thin, shelly, glauconitic limestone, while some distance above it another gritty bed of limestone equates with the level of Jukes-Browne's Bed 7 (see Fig. 17, p. 70). The available microfaunal data confirm this suggestion.

Although the overall correlation of the NE Province (Fig. 49) is very similar to that shown by Jeans (1968), microfaunal data permit a tighter correlation with the south-east of England. The area between Hunstanton and Leavening is shelf, north (Speeton) and south (Cambridgeshire) of which thicker sequences are recorded. More recently Jeans (1973) has reinvestigated the Market Weighton axis, and shown that basement faults apparently controlled the Cretaceous sedimentation.

d. North-west Province

Although the distribution proves a much wider initial coverage, the mid-Cretaceous of Northern Ireland and western Scotland occurs as small isolated patches of arenaceous deposits. M. B. H. obtained very little microfaunal data from these deposits.

In western Scotland (Bienn Iadain and Lochaline (Morvern); Carsaig, Loch Don, Alt na Teangaidh and Gribum (Mull); Clach Alasdair (Eigg) and Strathaird (Skye)) the macrofaunal evidence (Lee & Bailey 1925, Richey 1961) and the meagre microfaunal evidence give a Lower Cenomanian age for the glauconitic sandstones. The succession on Bienn Iadain (glauconitic sandstones, white sandstones, brown clays) is completely referable to the Cenomanian. In Scotland, as in Northern Ireland, there is a hiatus in the Turonian. In Northern Ireland the evidence shows in addition a period of intra-Cenomanian erosion preceding the main break in deposition. Here the lowermost unit of the mid-Cretaceous succession, the Glauconite Sands, contains a diagnostic Lower Cenomanian fauna (Hancock 1961, McGugan 1957, and our own collections), and equates with the glauconitic, calcareous sandstones of the Morvern succession. The Glauconite Sands of Northern Ireland grade upwards (Portmuck, Colin Glen, etc.) into the Yellow Sandstones that have been dated as Cenomanian (? Middle) by Hancock (1961). The intra-Cenomanian contact between the Yellow Sandstones and the overlying Upper Glauconite Beds is interesting in that it is picked out by a level of erosion and piping. The fauna of the Basement Sands (Zone of *Exogyra columba*) of the Upper Glauconite Beds is Cenomanian (Hancock 1961) and it is suggested tentatively that this intra-Cenomanian erosion surface relates to the mid-Cenomanian non-sequence. The occurrences of *Orbitolina concava* (Lamarck), recorded by Hancock (1961: 18) and Hume (1897) from the Basement Sands, have not been verified, and no examples of this species have been found in the Museum collections.

If the mid-Cenomanian non-sequence can be placed in the Northern Ireland succession, it may be possible to relate it to the succession in Scotland. The evidence already suggests the non-sequence to be responsible for the termination of sedimentation prior to the Turonian hiatus. If this is borne out by future work, it would be possible to correlate the mid-Cretaceous arenaceous sediments of the NW Province directly with those in the Lower Cenomanian (Zones 7-9, ? 10, ? 11(i)) of the south-east of England.

e. Mid-Cretaceous of northern France

The sections at Cap Gris Nez are so similar to those at Dover that they have been studied in less detail than those farther along the French coast, at Cap d'Antifer (Seine Maritime). The latter extend from St Jouin to just east of the Cap, where a small valley allows access to the beach. This section (Fig. 50) has been described by Juignet (1970), whose ammonite determinations are accepted here. This cliff section is very different from those in the Lower Chalk of south-east England. The chalk contains very little clay material - unlike the Chalk Marl - while flints and cherts occur in large numbers. Hardgrounds, with associated phosphatized faunas, occur at

CAP D' ANTIFER

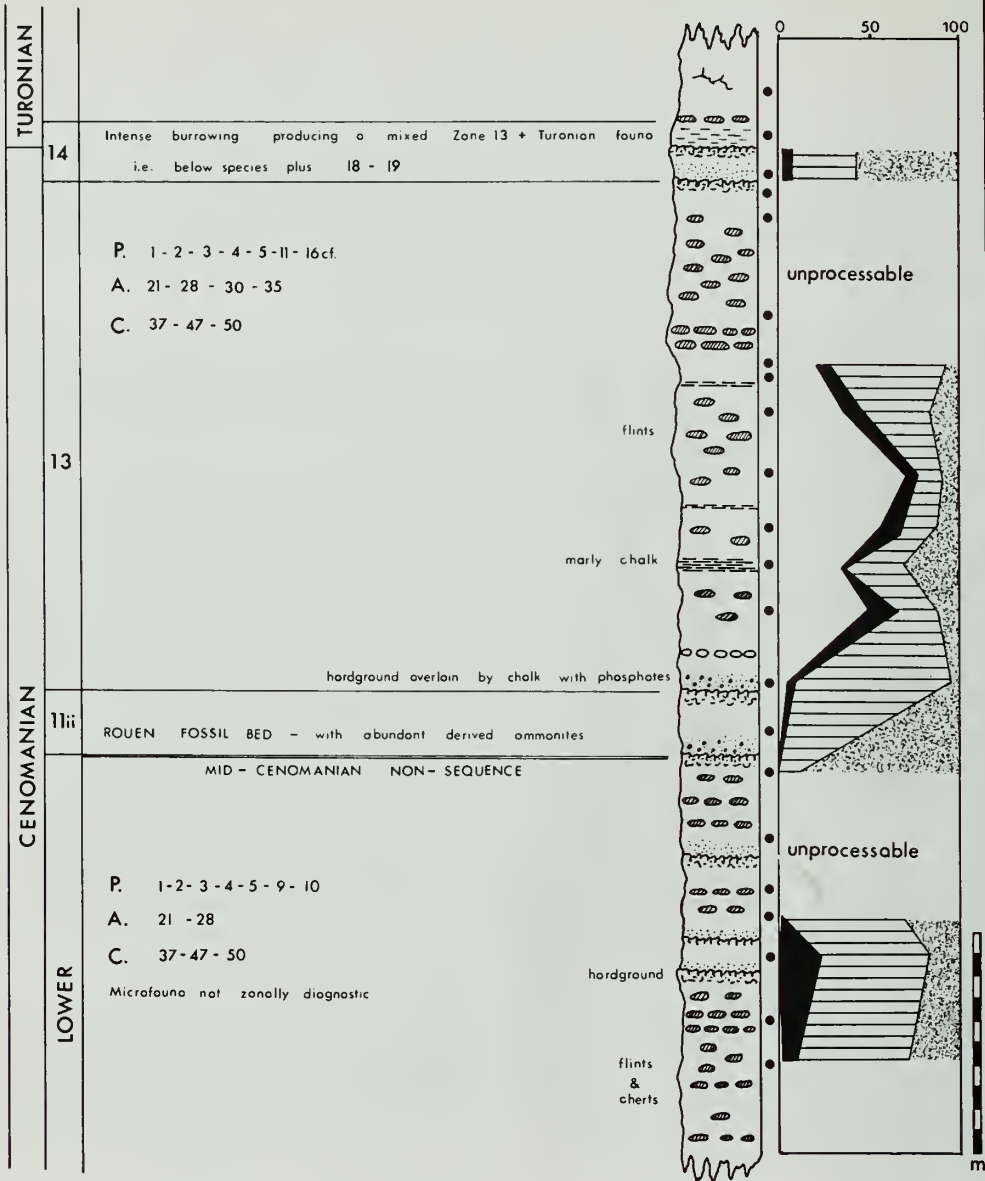


Fig. 50 Microfaunal details, Cap d'Antifer, Seine Maritime, France. The ornamentation used in the planktonic/benthonic ratio graph is explained in Fig. 12c. See Fig. 20 for key to letter code.

regular intervals and are reminiscent of the erosion surfaces in the Cenomanian Limestones. Although the microfauna has not been studied in detail it fits into the British microfaunal zonation. The thickness of the Cenomanian at Cap d'Antifer is approximately 40 m, which is a marked reduction from the 76–78 m recorded at Dover. The most prominent feature of the succession east of Cap d'Antifer is the phosphate bed which is the lateral equivalent of the mid-Cenomanian non-sequence. It was equated with the Rouen fossil bed by Juignet. It contains a Zone 11(ii) microfauna, and we agree with Juignet's correlation. Immediately above this horizon at Cap d'Antifer there is another hardground which is followed by 13 m of chalk with flints. The fauna of this chalk is of Zone 13, which agrees with Juignet's (1970) suggestion that it belongs to the Middle and Upper Cenomanian. The upper hardground also marks the appearance of pyrite nodules in the Cenomanian succession, thus agreeing with their appearance in Britain close to the base of Zone 13. The *Actinocamax plenus* Subzone is represented by two thin limestones higher up the succession. Below and between them are phosphatized hardgrounds. The lower hardground corresponds to the sub-*plenus* erosion surface of Jefferies (1962, 1963), while the upper horizon appears to represent the pre-Bed 4 erosion surface of the British succession. The occurrence of *Metoicoceras gourdoni* (de Grossouvre) in the upper limestone bed agrees with this microfaunal determination. The central hardground is therefore the Cenomanian/Turonian boundary on the basis of the zonation proposed here.

The Lower Cenomanian below the mid-Cenomanian non-sequence at Bruneval Plage and St Jouin contains flints and cherts, both of which occur in bands that can be traced laterally for some distance. The cherts occur below the mid-Cenomanian non-sequence, and not above. Since the Chert Beds in south-west England have been assigned a post-diagenetic origin, initiated at the time of the mid-Cenomanian non-sequence, this fact may be significant. The lower levels of the succession have not been sampled in detail and no firm zonal determinations have been suggested.

We have accepted the correlation of Rouen with Cap d'Antifer proposed by Juignet (1970). At Côte Ste Catherine the famous Rouen 'Fossil Bed' represents the mid-Cenomanian non-sequence, with its associated Basement Bed fauna of derived ammonites. The Cenomanian chalk above this hardground is only some 2.0 m thick, and is overlain by a layer of glauconitized pebbles which represent derived remnants of the *A. plenus* Subzone (Jefferies 1963; Kennedy & Hancock 1970). The microfauna (Fig. 51) of this chalk is completely in accord with a Zone 13 determination. This apparently conflicts with the published data, which indicates a Middle Cenomanian age for the Rouen Chalk. Kennedy & Hancock (1970) state that the Fossil Bed at Rouen is younger in aspect than at Snowdon Hill (Chard) (Fig. 34, p. 91), but they compared accumulations of derived ammonites representing a larger part of the Middle–Upper Cenomanian interval. The chalk above the Basement Bed at Chard is of Zone 13 age, as at Rouen. The Cenomanian fauna disappears completely at the base of the line of glauconitized pebbles, which represents the Cenomanian/Turonian boundary. We would disagree with Jefferies' (1963) suggestion that the main erosion level was that below the line of pebbles. A much greater hiatus is represented by the Fossil Bed – at the level of the mid-Cenomanian non-sequence.

A traverse south-west of Rouen nearer to the type area of the Cenomanian (Fig. 1) has been described by Juignet (1971: fig. 4) and this can be placed in our microfaunal succession with little difficulty. The most interesting aspect of Juignet's work is the detection of an 'axis of sedimentation' running south-east through Le Merlerault. The Lower Cenomanian succession of the 'Craie Glauconieuse' appears similar on both sides of this axis, while the overlying Middle and Upper Cenomanian sequence is completely different. To the north of the 'axe de Merlerault' the Middle and ? Upper Cenomanian is in the 'Craie de Rouen' facies which continues to the Channel coast. To the south-west of it the succession is considerably thicker, and the change is comparable to that seen when crossing the North Norfolk Swell from north to south. The Upper Cenomanian is represented by the 'Sables du Perche' and the 'Marnes à Huîtres'. The mid-Cenomanian non-sequence in the Sarthe is immediately overlain by the 'Craie de Théligny', which is especially well developed in the area to the north-east of Le Mans. At Les Aulnais, near Théligny, the phosphatized fossil bed, typical of the non-sequence, rests on a very resistant calcareous sandstone which is reminiscent of the Eggardon Grit of the south-west of England. The faunal relationships are almost identical with those at Eggardon Hill in Dorset (Fig. 40). To the south of Le

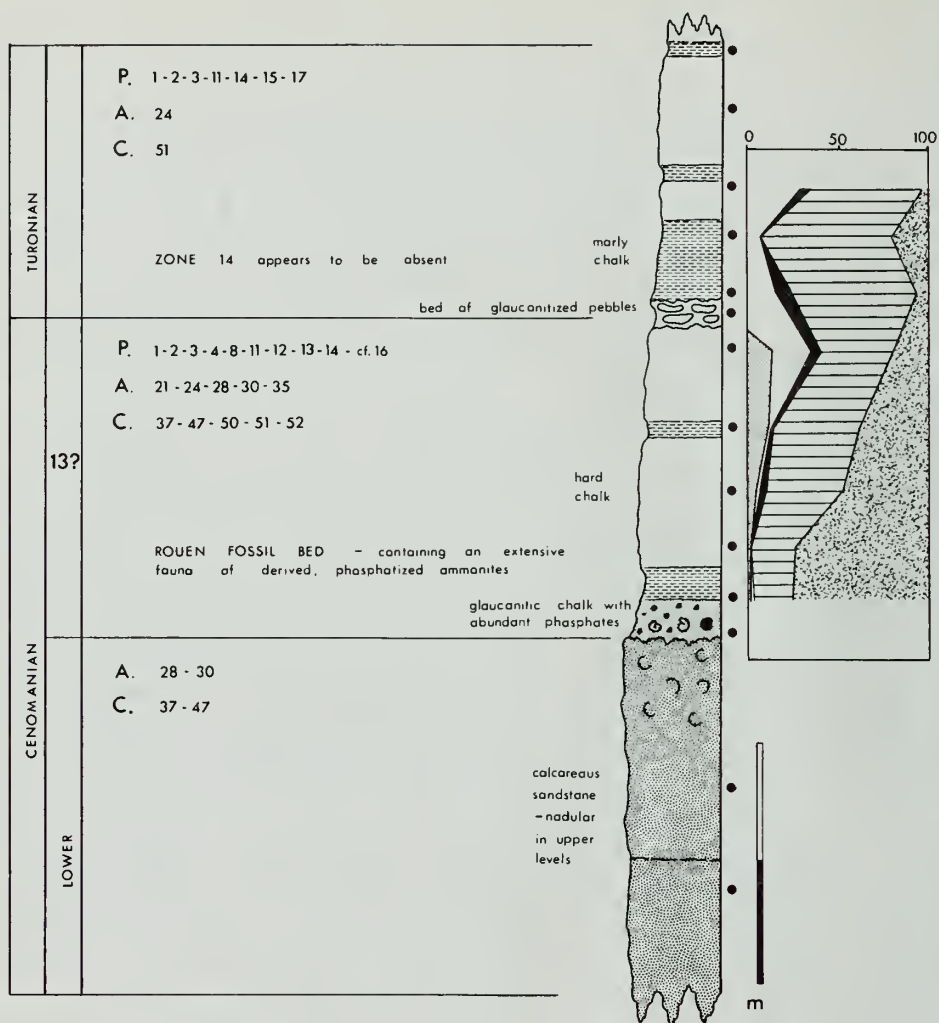


Fig. 51 Microfaunal details, Côte Ste Catherine, Rouen, France. The ornament used in the planktonic/benthonic ratio graphs is explained in Fig. 12c. See Fig. 20 for key to letter code.

Mans the mid-Cenomanian non-sequence is lost in the complex successions of the 'Sables de Maine'. The Upper Cenomanian of this area has already been discussed in the section on the Cenomanian/Turonian boundary.

The most interesting feature of the 'axe de Merlerault' is that its trend is almost parallel to those plotted in the south-west of England, and appears to belong to the same structural suite. The same trends appear again in north-east France where both Jefferies (1963) and Robaszynski (1971) have described the succession in the quarry behind the station at Bettrechies, 4 km north-west of Bavay (Nord). The 'Sarrazin de Bellignes' was regarded as Middle Cenomanian by Marlière (1939: 356, fig. 36; 1965) while Robaszynski places it within the Lower Cenomanian. The overlying 'Tourtia de Mons' contains a microfauna which indicates a position within Zone 14(i-ii). The overlying chalk contains elements of a Turonian fauna, and was included within the 'couches à grosses globigérines' by Robaszynski (1971). The relationships are very similar to those at Membury where a 'tourtia' is overlain by glauconitic chalk containing a Zone 14(i-ii) fauna. At Membury the underlying greensand may be comparable with the Sarrazin, although we have no faunal data from this level. The two successions are compared in Fig. 52. It is significant that *Inoceramus labiatus* first appears 1 m up the succession at Bettrechies. The position of the first appearance of *I. labiatus* at Membury is not known as there is a gap in the exposures at this critical level.

Marlière (1965) suggested that the 'Tourtia de Mons', when traced into the centre of the Anglo-Paris Basin, could be equated with the Totternhoe Stone. This correlation has proved correct, but we place the mid-Cenomanian non-sequence at the upper surface of the Totternhoe Stone and not the base, as indicated by Marlière.

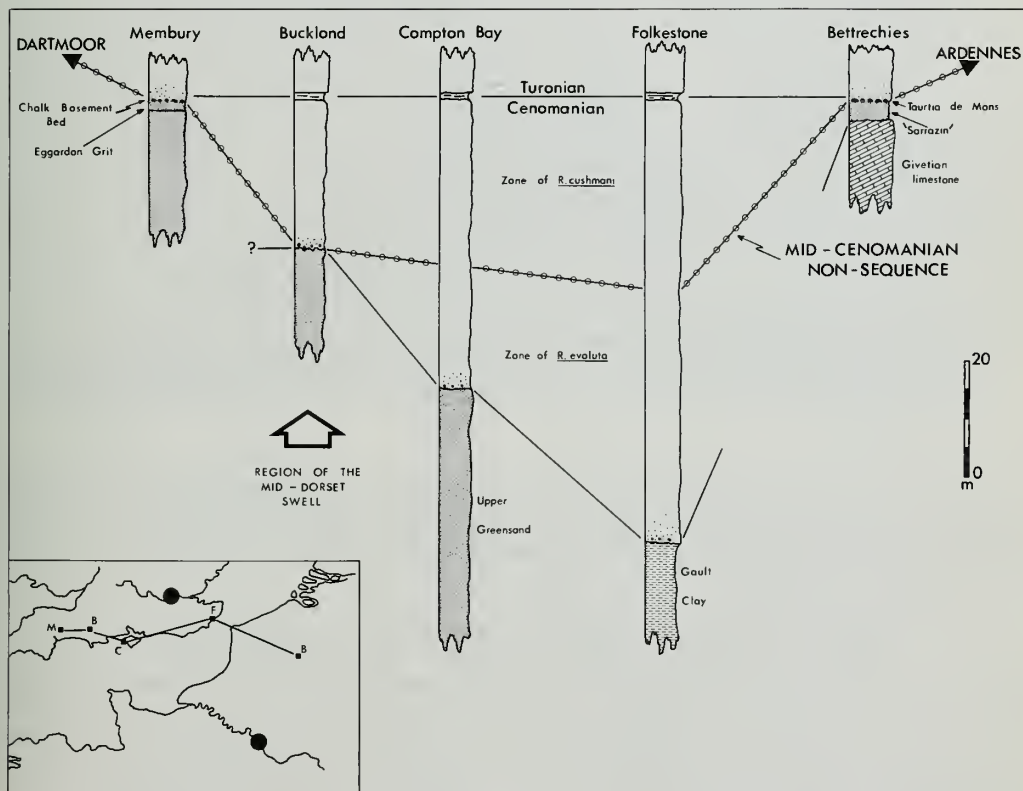


Fig. 52 Submergence of the Dartmoor and Ardennes Massifs.

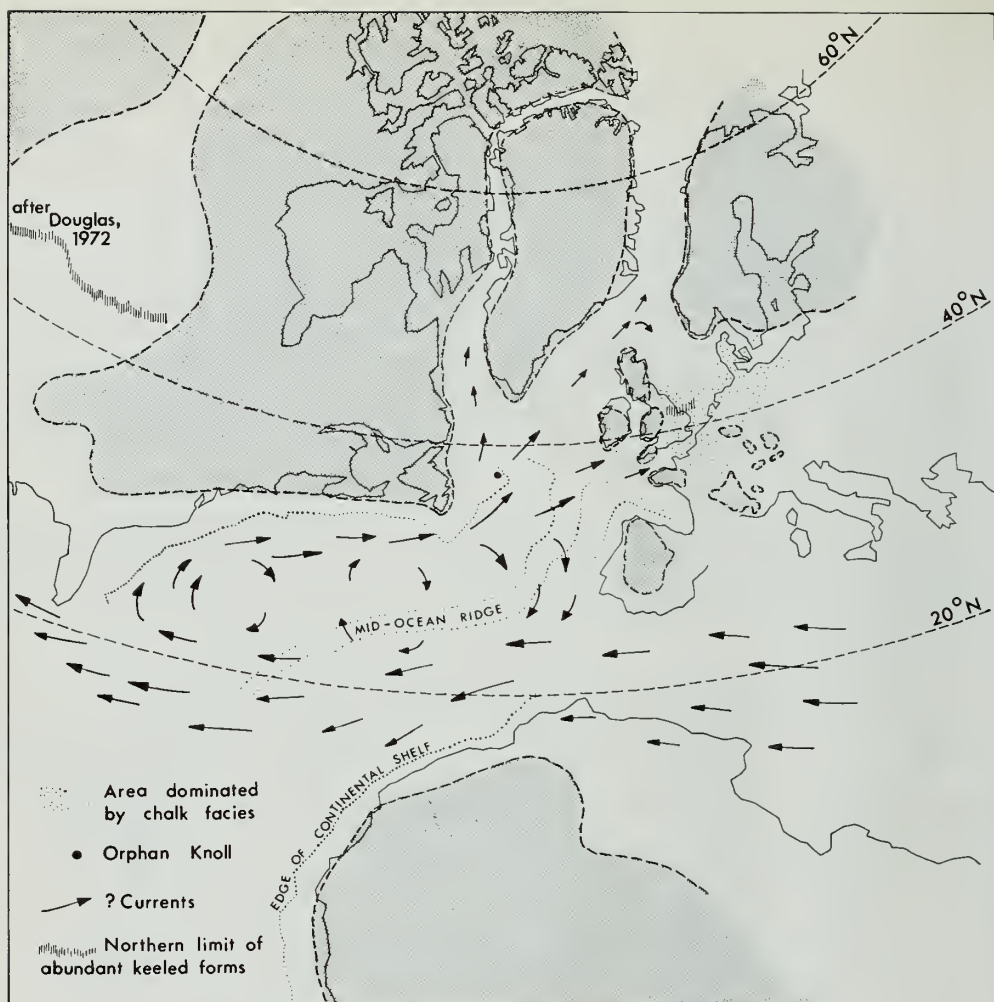


Fig. 53 Upper Cenomanian palaeogeography of the North Atlantic Ocean and surrounding areas (base map from Hart & Tarling 1974). The palaeocurrents are based on the work of Luyendyk *et al.* (1972), modified by the present authors in the light of palaeontological information (Hart & Carter 1975).

The mid-Cenomanian non-sequence has been traced successfully across the whole of the Anglo-Paris Basin from central France to northern England, and from East Anglia to Devon. The following section attempts to relate the work in NW Europe to more speculative studies of the development of the North Atlantic Ocean.

Mid-Cenomanian changes in North Atlantic palaeogeography

The important changes occurring at the level of the mid-Cenomanian non-sequence in NW Europe probably relate to the development of the North Atlantic Ocean. Dr D. H. Tarling (University of Newcastle) has kindly provided the authors with a reconstruction of the Cenomanian (100 Ma) North Atlantic Ocean based on palaeomagnetic data. This is shown in Fig. 53. The discussion pertinent to the reconstruction is included in a separate account (Hart & Tarling 1974). This reconstruction has been used to plot the approximate positions of the Cenomanian

shorelines (based on the mid-Cenomanian). Britain and France are seen to fall in the centre of a large island-studded shelf area which lay at about 40°N. In a synthesis of the palaeogeography the following items are relevant.

i. The planktonic/benthonic ratio

This subject has already been discussed (11-62-65) and no further comments will be added.

ii. The occurrence of the keeled planktonic foraminifera

In modern oceans keeled planktonic foraminifera are generally restricted to regions within the 17 °C surface water isotherm. Bandy (1967) plotted '*Globotruncana/Rotalipora*' lines through the Upper Cretaceous, north (or south) of which keeled planktonic individuals have not been recorded in large numbers. Bandy related this distribution to the palaeotemperature work of Urey *et al.* (1951), Lowenstam & Epstein (1954) and Bowen (1961), all of which was based on data from NW Europe. This shows that in the mid-Cenomanian the British area was at the temperature limit for keeled planktonic individuals. However, in modern oceans the 17 °C surface water isotherm usually lies within the latitudes 20°N and S, although it may extend to 40°N and S in areas affected by oceanic currents. Bandy (1967) indicated that in the European Cenomanian keeled forms extend into latitudes as far north as 48°N, although they are recorded in large numbers from East Anglia at latitude 52°N. While this suggests that there is some variance in the Cenomanian between the postulated temperature control or the latitude and the distribution of keeled forms, this is largely cancelled out in our palaeogeographical reconstruction, which places southern England in the region of 40°N. The rapid increase in the palaeotemperatures for the Turonian appears to have been initiated in the mid-Cenomanian, and while possibly attributable to the general warming reported in the Upper Cretaceous, it may be related in part to other factors.

The British planktonic occurrences originally lay very close to the 40° northern limit, and probably relate to the abundance variations of keeled and non-keeled forms recorded in the Cenomanian (Fig. 12). Two possible causes for these variations can be suggested. The first involves slight climatic oscillation, while the second, more likely, is the periodic influx of warm water into the European area. The effect of even slight movements would, in such borderline conditions, be sufficient to cause a local influx of keeled individuals. In the Middle Cenomanian only isolated peaks of keeled forms are recorded; they become more persistent in the Upper Cenomanian. In the Turonian a steady population of keeled forms is recorded, even though Britain and Europe were drifting northward at the time.

The evidence suggests that (i) the depth increase recorded in the mid-Cenomanian allowed the influx of warmer oceanic water by drowning the marginal zone of islands shown in the palaeogeographical reconstruction, and (ii) that the water masses flowed into this area intermittently at first, but later became more constant.

iii. Phytoplankton production

Tappan's work on phytoplankton productivity (1968) shows a slight increase in the production of calcareous phytoplankton in the mid-Cenomanian. In modern oceans areas of rapid phytoplankton increase occur where mixing of water masses takes place. This is particularly true in the North Atlantic, off Newfoundland, where the Gulf Stream impinges against the cooler water emerging from the Labrador Sea. The area of greatest coccolith concentration in surface sediments forms a spur towards the European area, with high figures shown off the Portuguese coast. The production of organic carbon also shows a high in the north-east Atlantic Ocean. Both of the latter occur where the warmer water impinges on the shelf water of NW Europe, and it is possible that similar factors were operating in the Upper Cretaceous.

The Upper Cretaceous deposits of NW Europe (particularly of Great Britain and France) consist of considerable thicknesses of coccolith ooze, now in the form of chalk. This concentration could be attributed to the influx of warm water into an embayment of a shelf sea in temperate latitudes.

iv. Calcimetry of the Cenomanian

Destombes & Shepard-Thorn (1971) have provided data on the calcimetry of the Lower Chalk of the south-east of England as part of the Channel Tunnel Site Investigation. Their work has shown that CaCO_3 percentages of 80–95% are attained only above the mid-Cenomanian non-sequence, although there is an increase from 50–70% below that level. Once the level of 90% is attained, above the non-sequence, it is held, with minor fluctuations, at that level throughout the remainder of the Upper Cretaceous. The relationship of the calcimetry increase to the postulated increase in phytoplankton production is quite striking.

v. Faunal diversity

Valentine & Moores (1970) have shown it possible to relate faunal diversity to plate movements. On the break-up of Pangaea in the Triassic the standing level of diversity in the fragments increased steadily throughout the Jurassic, but less rapidly in the Late Jurassic and Early Cretaceous. In the mid-Cretaceous (c. 100 Ma) which, according to Valentine & Moores (1970), coincided with a widespread transgression, another sharp increase in the standing level of diversity occurred. This latter increase is traceable as starting at about what is now the level of the mid-Cenomanian non-sequence. Such a change could be expected to coincide with a depth increase and the development of a different ocean circulation pattern, particularly when the newly-forming South Atlantic Ocean is considered.

vi. Coiling directions in planktonic foraminifera

The coiling direction of planktonic species, particularly *Globorotalia pachyderma* (Ehrenberg) and *Globorotalia truncatulinoides* (d'Orbigny), have been used for the correlation of Pleistocene oceanic sediments. In general terms the greater the percentage of dextrally coiled individuals the warmer the water conditions prevailing, and *vice versa*. In the Cenomanian, there is an admixture of coiling directions, although the majority of individuals in the Upper Cenomanian are dextral. Both the *Rotalipora cushmani* and *R. greenhornensis* populations follow this rule, while the *Praeglobotruncana* spp. population is more variable. In the Lower Cenomanian the latter (largely *P. delrioensis*) is 50% dextral, while the Upper Cenomanian population (largely *P. stephani*) is generally 90% dextral. The groups that evolved from this stock (*P. algeriana*, *P. hagni* and *Globotruncana* spp.) are also similarly coiled. Although the change from 50% to 90% dextral coiling in *Praeglobotruncana* spp. appears gradual, it is initiated above the level of the mid-Cenomanian non-sequence. This is also true of *R. cushmani*, as populations from immediately above the non-sequence show a lower percentage of dextrally coiled individuals than ones from nearer the Cenomanian/Turonian boundary.

The planktonic/benthonic ratios, distribution of the keeled planktonics, calcimetry, faunal diversity and the changes in coiling direction of planktonic species all indicate that although an island barrier to NW Europe existed in the Lower Cenomanian, it was greatly reduced at the time of, and just after, the mid-Cenomanian non-sequence. The reduction of this barrier would have provided access for warmer, oceanic water, and the gentle subsidence of the whole shelf area would have allowed the continuation of marine sedimentation characterizing the Upper Cretaceous of NW Europe. This is the reverse of the situation in Colorado described by Eicher (1969a), where the evidence suggests that the seaway began to silt up in the Turonian. Fig. 11 (p. 62), shows the correlation between Eicher's Colorado succession and the Isle of Wight (Culver Cliff) sequence. The Zones of *Rotalipora cushmani* and *R. evoluta* in the two sections can be directly correlated, as can the change to a predominantly planktonic population in the mid-Cenomanian. In Britain the calcareous, plankton-rich succession continues into the Turonian while the sequence in Colorado indicates a gradual disappearance of plankton-sustaining conditions, and a reversion to clastic sedimentation.

The data also suggests a warming of the Cenomanian sea in NW Europe above the mid-Cenomanian non-sequence. Supporting evidence is now available from the Deep Sea Drilling Project cores in the North Atlantic area. Site 111 (Leg 12) at Orphan Knoll (NE of Newfoundland)

provides an interesting section through the mid-Cretaceous (Laughton *et al.* 1970, Laughton *et al.* 1972, Ruffman & van Hinte 1973, van Hinte, Adams & Perry 1975). In the core, the Albian and Lower Cenomanian sandy limestones (with *Rotalipora evoluta*) are overlain by Maastrichtian chalks. The hiatus occurs at possibly our Zone 9/Zone 10 non-sequence, or more probably the more important mid-Cenomanian non-sequence. Several workers (e.g. Ewing *et al.* 1970a, Hayes *et al.* 1971, Vogt *et al.* 1971, Habib 1970) have discussed the mid-Cretaceous sedimentation of the proto-Atlantic Ocean, and Vogt *et al.* have postulated an oceanic current system in the eastern Atlantic during the Lower Cretaceous (Fig. 53). It is considered that the depth increase postulated for the mid-Cenomanian, and the resulting Cenomanian 'transgression', not only ultimately drowned the islands shown in Fig. 53, but also allowed the development of water circulation across the drowned crest of the mid-Atlantic ridge. The passage of warm water over the Newfoundland Banks area could have produced a strong current through the relatively narrow straits between Spain and North America. This would then have produced the phosphatized hardground and the stratigraphic hiatus recorded at Orphan Knoll. With the opening of the Labrador Sea later in the Upper Cretaceous, water movement could have been deflected away from Orphan Knoll by a southward flow between Greenland and Canada. Mixing of the warm Atlantic water with the cooler southward-moving stream might have provided the stimulus to phytoplankton growth required to produce the Maastrichtian chalks recorded at Orphan Knoll.

It is impossible to say at present if part of the moving water mass turned southwards forming a true gyre. There seems to have been little influx of cold water into the main body of the Atlantic Ocean, as the first arrival of cold Norwegian water marked by the appearance of the cherts in the sea-floor sediments does not occur until the Lower-Middle Eocene (Ewing *et al.* 1970b). The currents in the Upper Cretaceous would also be affected by the flow of water through the Central American isthmus which was to remain open well into the Tertiary.

In NW Europe, during Late Cretaceous times, warm waters must have flowed from the southwest into an embayment (lat. 30°–45°N) into which there must have been some supply of cooler, nutrient-rich water (from the north ?). This, on upwelling adjacent to the nearby coastline, would have stimulated phytoplankton production, and so induced carbonate sedimentation.

Although there is insufficient evidence to prove that the North Atlantic current pattern was initiated in the mid-Cretaceous, there is an indication of fundamental changes at that time which affected the whole Upper Cretaceous history of NW Europe. Work on this problem is still in progress, but it is hoped that this interim report may be of some value in our understanding of the stratigraphy of the Cretaceous System in this area.

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